condenser was developed and is now used for 50, 60, 500, 1,000 and 3,000 Hz. The loss on the induction element shows a decrease by approx. one digit. For instance, the all-film condenser for 1,000 Hz indicates the value "tan $\delta = 0.025$ at 40° C", while the conventional mineral oil-impregnated paper condenser shows tan $\delta = 0.26$. The capacity of the condenser for high frequency furnaces (600 kW–1 ton–1,000 Hz) is approx. 7,000 kVA. However, if the paper condenser is replaced by the all-film type, the loss would be reduced by approx. 16.4 kW or an energy saving of approx. 2.74 % against power input.

(2) Frequency converter

In the frequency converter for high frequency furnaces, the motor-generator type was used extensively. However the thyrister-type high frequency invester is now available at reasonable prices. The conversion efficiency of the motor-generator type is approx. 85% at 1,000 Hz and 600 KW. On the other hand, the said efficiency of the thyrister-type inverter is approx. 95% or a difference of approx. 10% under similar specifications.

In addition, the thyrister-type inverter performs the matching of load impedance by changing the frequency automatically. For this reason, this type shows a higher load factor than the motor generator type, and also cuts down the melting time.

If the motor generator-type inverter is replaced by the thyrister-type inverter, energy can be saved approx. 15%.

(3) Water-cooled cable and bus bar

Since the electric power circuit is a low-voltage high amperage circuit, the bus bar and the water-cooled cable have an electric current density of 10 to 15 A/mm^2, the wiring loss is heavy.

For example, the current for the crucible-type low-frequency furnace (1,200 KW—5 t—1,200 V) is approx. 5,000A. In this furnace, two pieces of water-cooled cable (400 mm^2 – 6 m), both ways, are used. If this number is doubled, an energy conservation of approx. 1% will be achieved.

(4) Load factor

A) For furnace voltage, it is suggested that the max. tap be used to make the max. electric power, as far as circumstances allow. But this should be carried out, considering the effect on refractories.

B) In the case of the crucible-type low-frequency furnace, if molten metal in the furnace is equivalent to more than 60% of the rated quantity, it is possible to apply a rated electric power. It is recommended that at least more than 50% of the molten metal be left in the furnace and a make-up charge be made. This cycle should be repeated to dischage molten metal.

C) Raw materials should be large enough in size within the limit to be easily charged into the furnace.

D) When using a starting block, the height of the block should be almost the same as that of the coil.

(5) Temperature control

A) The temperature for discharging molten metal should not be raised beyond a reasonable level. Generally, the said temperature tends to be set higher than it should reasonably be, considering the smooth discharge. For instance, when melting cast iron, it is possible to reduce the unit electric power consumption rate by 15 to 20 kWh/t, if the temperature is lowered by 50°C. Arrangements should be made satisfactorily for operation up to the discharge so that an operational temperature drop may be prevented and the discharge temperature may be at a low level. In addition, if the measurement of temperature were delayed during the ascent of temperature, molten metal would be over-heated by 20 to 30°C for the crucible type low-frequency furnace and 60 to 90°C for the high-frequency furnace. Thus, a loss on the unit electric power consumption rate would be 10 to 40 kWh/ton.

B) The thermometer should be maintained in order and calibrated periodically. There is often such an occasion that thermometer readings at the high temperature (1,600°C) show an error of 20 to 30°C. In order to prevent any unnecessary overheating, make sure that the thermometer is calibrated carefully.

(6) Prevention of cooling of furnace

A) The frequency of operating the furnace lid should be minimized. The heat radiation loss of the furnace is proportional to the exposing area and is proportional to a value obtained by raising the absolute temperature of molten metal fourth power. Therefore, make sure that the furnace is covered with a lid as far as circumstances allow during melting. For instance, when cast iron is being molten in the 8-ton crucible-type low-frequency furnace, a loss of radiant heat from molten metal at 1,500°C amounts to approx. 150 kW. So if the furnace lid is left open for 10 minutes for discharging slag or adjusting components, the loss will be approx. 10 kWh/t in terms of the electric power consumption rate.

An example of the effect of the furnace lid on electric power for retaining heat is shown in Fig. II-4-72.

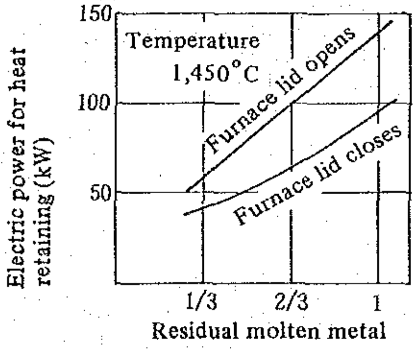


Fig. III–4–72 Effect of furnace lid on electric power for heat retaining (used the 2-ton crucible-type low-frequency furnace at 600 kW for measurement)

B) If the supply temperature of cooling water is low, it cools the furnace wall, thus, increasing the loss of heat transfer. On the other hand, thanks to the reduction of power loss at the coil copper tube and water-cooled cable by lowering temperature.

This tendency tends to be conspicuous on furnaces with high power supply. Therefore, it is better to decrease the temperature of the coil- or water-cooled cable with a great amount of cooling water, unless there is any impediment due to dewing.

For instance, the 2-ton acidic refractory furnace, at a capacity of 1,200 kW and 500 Hz, would show an increase in efficiency of approx. 0.8 to 0.9% at 10°C. In addition, the lower the cooling water outlet temperature becomes, the less chance for fur formation.

(7) Execution of continuous operation

It is desirable to operate the furnace continuously. The furnace uses a large quantity of refractories, so the regenerated heat capacity of refractories is high when the furnace begins to be operated at room temperatures, as in the batch operation. For instance, in order to reach 1,500°C of furnace wall temperature, an electric power of approx. 650 kWh is required for the 8-ton crucible-type low-frequency furnace using approx. 2.7 tons of silica refractories, and approx. 170 kWh for the 2-ton high-frequency furnace using approx. 0.7 tons of silica refractories.

(8) Removal of impurities contained in charged raw materials

Raw materials for melting often contain impurities such as casting sand and oxides. Especially if the return scrap with fused casting sand is charged, in the furnace, casting sand and oxides are melted, causing the electric power consumption to increase. In addition, the heat loss due to slag removing will increase and the life of refractories will shorten. Also, slag sticking to the furnace wall will reduce the applied electric power, thus whittling down the production capacity. For instance, if 1% of sand and oxides is mixed in with the raw materials for melting into cast iron, the unit electric power consumption rate will increase by approx. 10 kWh/t.

(9) Casting process

The molten metal pouring quantity and the melting quantity will be reduced if the mold with less fin is used. Further, fuel will be saved by a curing method using a non-thermal hardening organic chemical when making a mold.

III. Guideline for Rationalization of Energy Use

5. Chemical and Plastic

Contents

1. Character of Guide Line

This Guide Line is a summary of technical matters considered important for the promotion of energy saving at the factories of the chemical and platic industries. The Guide Line is to be used for the following purposes.

1) (1) As technical reference for factory's engineers when they plan to rationalize use of energy in the factory.
   (2) As a diagnostic guidance manual.
   (3) As referential data for determining the progress of rationalization.
   (4) As a text for seminars.

2) Descriptive level which should be understandable by engineers having only 4 to 5 years' experience of actual service after college graduation, but not actually working in the subject industries.

3) In consideration of the present industrial status of the Kingdom of Thailand, the descriptive coverage is limited to the process-related matters of the factories which we diagnosed. Also, the basic items and numerical values regarding this process —energy-saving techniques and referential instances or actual records — are described.

It is hoped that the Guide Line prepared here will be further supplemented and substantiated by the addition of information obtained in future through NEA's own factory diagnosis and other means.

For information, the Guide Line contains standard values published by the Japanese Government (Ministry of International Trade and Industry) as a basis for judgement in promoting energy saving for factory managers through its notification.

(1) The standard values are the most frequent values (refer to Fig. III-5-1) of statistical distributions of numerous examples. As such they represent a realistic level for factory managers to attain without difficulty from the technical and economic points of view.

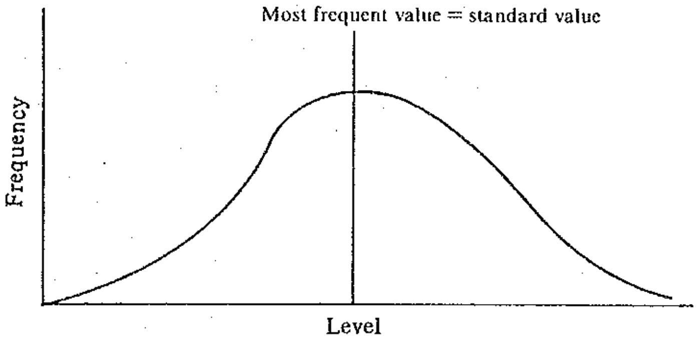


Fig. III-5-1

(2) The standard values do not necessarily represent the values which factory managers should be satisfied with after reaching them and also the minimum values which it must reach by all means. These values are rather those designed to improve the inferior value toward an average level, thus shifting the whole distribution of values into a better direction. Therefore, the most frequent value will be resought and a new standard value established after the elapse of a certain period.

The standard value establishment plan described in the report was prepared based on these standard values considering the present industrial status of the Kingdom of Thailand.

These standard values will be a starting point for the establishment of standard values for the rationalization of energy use in industry of the Kingdom of Thailand. It is recommended that the Kingdom of Thailand itself accumulates data during factory diagnosis to be put into practice, and evaluates it periodically and revises or newly establishes standard values.

2. Characteristics of Energy Consumption

(1) Chemical industry utilizes a change in quality, namely, chemical reaction in processing raw materials in major production processes. Moreover, physical and chemical treatment processes aim at pretreatment of raw materials, separation of products, refinery, etc. are added to complete one production train, which is called "Process Industry". Since few operations of each equipment in a chemical plant are generally performed at almost atmospheric temperatures, there are very many processes involving heating and cooling of raw material and intermediate products, etc., resulting in much energy consumption. It leads to rationalization in the use of energy to select the optimum temperature, pressure and concentration, etc. to ensure the highest efficiency in each operation, and to recover as much sensible, latent, and waste heat as possible during heating and cooling for effective utilization. Taking the case of an ethylene plant, a raw material, naphtha is cracked at a temperature of 800 to 850° C to manufacture ethylene and as much thermal energy as 6.5×10^6 kcal per ton of ethylene is required.

Taking the case of the ethylene plant which is striving for energy conservation, cracked gas and cracked fuel oil which are produced in this plant are used as fuel for the cracker and high temperature gas from the cracker provides waste heat boilers with heat in the quenching process to recover steam with miscellaneous temperature and pressure. This recovered steam is utilized separately for power, for reaction, and for heating according to the respective temperature and pressure. As a result, 17% of the heat input to the cracker is used for cracking reaction and after that, 68% is recovered: cooling loss and exhaust loss from the stack are only 15%.

(2) It is difficult to discuss energy conservation in chemical industries uniformly, because production processes and use of energy are respectively peculiar to the product and raw material used.

However, a similar process is, in most cases, used in spite of different processes with an unit equipment in which so-called unit operation is performed among processes and there are many points in common also in the use of energy. Hence, this standard proposal will select and discuss several typical unit equipments in use for chemical industries. For reference, one example of process flow of a chemical equipment is shown in Fig. III-5-2.

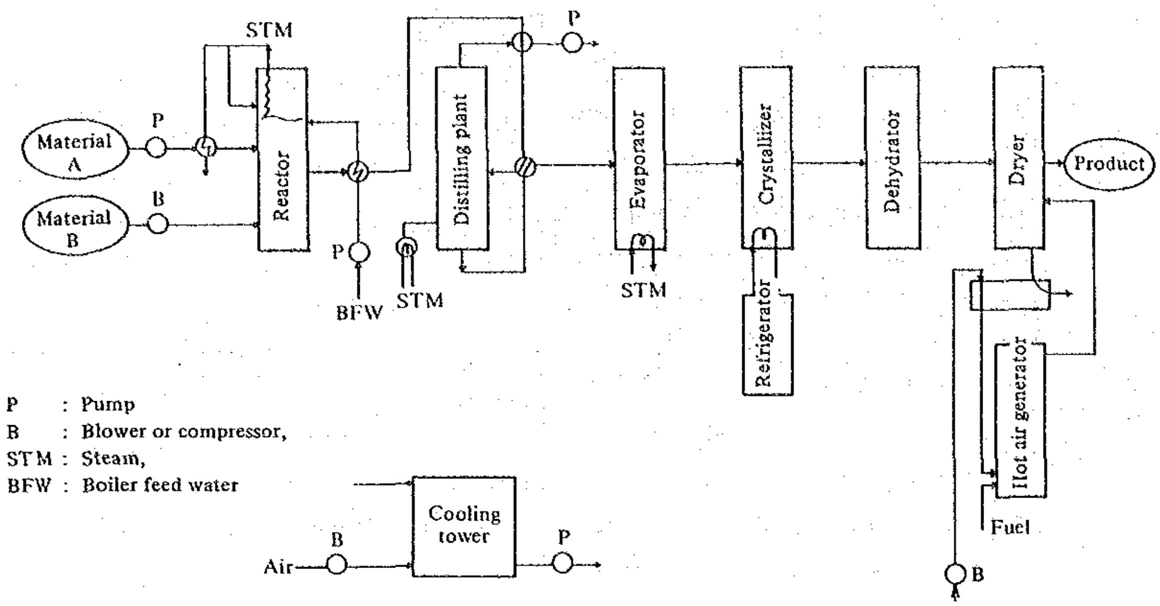


Fig. III–5–2 Flow sheet of chemical equipment (Example)

3. How to Manage Energy

In order to improve the efficiency of energy consumption, productivity and product quality as well as raise their overall level, it is essential first to use facilities well adjusted and maintained to the purpose and to operate them correctly. It is most effective for energy conservation to reduce the incidence of equipment failure and increase product yield. Secondly, it is required that those engaged in energy management study the possibilities of further improving the existing facilities and operating method and pursue better means through repeated surveys and factory experiments.

Accordingly, it is not exaggerating to mention that the consciousness and willingness of the total factory employees would influence the actual performance of the factory. And it is important to raise the level of factory management which encourages the employees to have such consciousness and willingness. It is defined that energy management is a systematic effort to achieve energy conservation.

3.1 Clarification of Management Policy

Following the soaring of energy prices, the factory owner and manager have grown more concerned about energy conservation. In order to promote this tendency on a company level instead of letting it merely stay within the frame of the owner's mind as a desire, it needs to be clarified toward all the employees that the top management has the intention to tackle the energy conservation problem seriously as a company policy. In positive terms, the target should be clarified quantitatively; such as what percentage of energy consumption per ton of finished product should be reduced. Simultaneously the restrictions such as the ceiling of annual investment and deadline for pay back time should be clarified.

As explained above, the top management should clearly show the way to proceed on to the employees. Then in turn, the latter become confident about their jobs meeting the direction set by the former. Further, both can develop a smooth collaborative relationship because everybody involved is spiritually aligned in a unified direction.

Since the target of the top management is shown as a comprehensive one for the whole factory, each section and department should set concrete subtargets which do not require too much time and try their best effort to achieve these subtargets. These subtargets should be set concerning items for which any counter-measures can be taken by section and department personnel within their own responsibility range to attain the target set by the top management. As the said target is shown in a familiar and understandable form, it is easy to expect even employees of the lowest rank to fully understand the subtargets and extend their cooperation in attaining them.

When setting subtargets for each section and department, it is suggested that the committee described later or others study if such subtargets would be appropriate for achieving the overall target.

3.2 Arrangement of System for Promotion

In a campaign, for energy conservation where various classes of people take part, persons who play a part to promote the activities of all as a nucleus. If the factory is small, an individual person may be a promoter, but if the factory is large, a section for promotion is sometimes established.

This position should be occupied by a top-notch person and he should always be careful about a progress in energy conservation status and look into a cause, if there is a delay, then try to treat problem.

In concrete terms, the assignments of the position are as follows: the grasping of actual energy consumption, comparison of actual energy consumption with plans, invitation and checking of ideas about improvement, budgetary distribution, management of work progress and evaluation of actual works, mapping-out of education programs, preparations for committee meetings, etc.

The committee is effective for adjustment so that inter-disciplinary understanding may be realized among sections and departments such as manufacturing, sales, raw material purchasing, equipment maintenance and servicing, and accounting, and countermeasures may be put into practice smoothly. At the committee meeting, any possible influence of energy conservation measures to be performed on each section and department should be studied to make sure that no profit is reduced on an entire factory basis.

It is important that a general manager of the factory or a person next to the former in rank who has responsibility and authority in production assume the chairmanship of the committee. Otherwise, no decision would be made, neither would such a decision be implemented.

Even if certain energy measures were based on an excellent idea, any fruitful results would not be expected unless the operator fully understands what the measures mean and applies them to the actual work. There are many cases where the QC (quality control) circle which is effective for quality control is utilized successfully for energy conservation with noteworthy results. The QC circle is an activity of improving human relationship in the job, stimulating people to become more conscious about independence endowed intrinsically to humans and providing them with the pleasure of working actively. However, it is necessary to prepare conditions which make the operator find it easier to conduct activities such as education and incentive granting before he can recognize the advantages and necessity of the circle activities. It is the operator on the front line that is always in touch with energy consuming equipment and sensitive enough to grasp any phenomenon appearing according to a change in the operating conditions. It is extremely effective for energy conservation to make the best of information obtained by the operator and to squeeze out a good idea for improvement.

3.3 Scientific and Systematic Activities

It is an indispensable condition to obtain an exact status of energy consumption when energy conservation is carried out. If data such as change of the unit consumption rate per production, difference in the unit, variation of product grade and difference in raw materials are not available, it would be impossible to formulate plans which guide you toward an area requiring the implementation of immediate procedures. In other words, it is factory data that provide numerous ideas for improvement. If studies are made of these data with a consciousness about problems, it would be able to find something leading to such ideas. Therefore, it is suggested that a measuring instrument be installed at necessary spots, record its readings and obtain information through their periodical arrangement. In this case, such data should be processed from the viewpoint of mathematical statistics to determine if the difference is significant.

Next, it should be made sure that the results are followed up, if improvement plans were implemented. Efforts should be made to enhance the quality of operations according to the PDCA circle advocated by Dr. Deming. The function of the PDCA circle is such as explained below as shown in Fig. III-5-3:

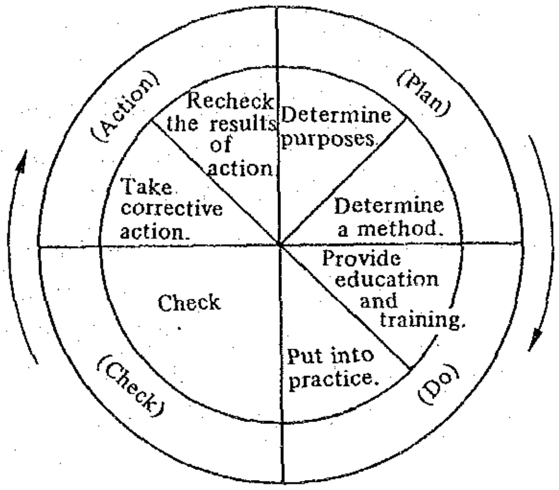


Fig. III–5–3 Deming circle

First, plans should be formulated; that is, a purpose will be set for a certain theme and means decided. This represents "P" for PDCA. People will be trained concerning how to perform these means and given an opportunity to actually do them. This represents "D". The results of the performance will be checked. This represents "C." Results of the check will be evaluated to determine if they are satisfactory. Action will be to standardize the results, if they are satisfactory and to take corrective measures if there is still a problem yet to be resolved. If one step was completed, the function of "PDCA" will be set to work towards a target of higher level. In this way, people proceed with their assignments. This method will be helpful for not only energy conservation but also heightening the quality of jobs in every field.

With regard to the part concerned with "Plan," it is recommended that "improvement plans invitation system" be actively utilized because items to propose can be found rather easily during an early stage. It should be so arranged that proposals may be made by whosoever he may be, an individual or a member of a working place, the QC circle or staff. Proposals presented should not be left alone, but should be examined promptly by the committee and others. The proposals presented should be adopted as far as circumstances allow after being modified on advice depending on the occasion. It is also suggested that a prize be presented to people for their proposals and further, a commendation be given to those whose proposals brought about fruitful results. These measures will be an incentive for people to deepen their consciousness about participation. For proponents whose proposals were not adopted, it is suggested that they be explained about the reasons why the proposals were not taken up and at the same time, be properly guided over better ideas.

In the stage of "D", it is suggested that satisfactory explanation be provided to employees of the lowest rank regarding an intention for improvement, and their cooperation in an effort toward the improvement be solicited. They are also encouraged to report even on minor abnormalities during operation so that they may be able to make scrupulous adjustments. This consideration is necessary to eliminate any possible cause for error.

"Check" should be conducted periodically and at the same time, the results be reported to the committee and the senior official. Along with this procedure, the results also should be made known to the operator so that he may deepen his concern. In this case, it is important to clarify an evaluation criterion from the beginning; it is not desirable to change it easily halfway.

If satisfactory results can be expected following the implementation of an improvement plan, they should be incorporated into the operation standard. Simultaneously necessary measures for the improvement of equipment should be taken so that any extra load may not be brought to bear on the operator. This is a condition for continued favorable results of energy conservation.

In case considerable results have been accomplished continuously as a result of the above, their summarized processes should be published as references. At the same time, those concerned should be officially commended so that they may be motivated for next activities.

3.4 Furnishing of Education and Information

Even if employees are willing to cooperate, any improvement can hardly be expected, unless they have knowledge as to how they should do it. They would become more positive to participate in the energy conservation campaign, if they are capable of presenting their own improvement proposal without being limited to merely pointing out problems. In order to realize this target, an internal education program sponsored by the company itself is important; that is, programs such as seminars and distribution of guide books should be provided. In the Kingdom of Thailand, a considerable number of companies are enthusiastic about education and also numerous cases where their staffers are sent for participation into external seminars are noticed. To our regret, however, such staffers sent for the external seminar tend to keep their acquired knowledge only to themselves instead of passing it on to other staffers or general operators. If it is arranged so that those who received external seminar training become lecturers for internal education and provide training to other people based on their acquired knowledge, it is expected that the entire level of employees' professional quality will be raised and staffers participating in the external seminars will be able to make sure that their obtained knowledge is practically useful.

Next, it is desired that information exchange with other companies of the same industry or raw material suppliers or finished product buyers be activated. Although it is naturally important that competition should take place among different companies of the same industry, it is recommended that technical information be exchanged to some extent on a give and take basis. This is because the technical level of the entire company can be heightened resulting in stronger international competing power and subsequent mutual benefit. For instance, the publishing of actual unit consumption rates will be instrumental for the motivation of commercial competition.

4. Rationalization in the Use of Thermal Energy

4.1 Basic Data

4.1.1 Combustion Equipment

(1) Fuel

A) Gaseous fuel

The typical gaseous fuel used for industrial purposes is natural gas. Its composition varies according to the gas field, but it generally has methane for its main component (88 to 99%), the heating value being 9,000 to 11,000 kcal/m^3.

B) Solid fuel

Lignite and coal are mostly used industrially and have heating values of 3,000 to 4,500 kcal/kg and 4,500 to 7,500 kcal/kg respectively. Their properties and composition greatly vary according to their places of origin.

C) Liquid fuel

Liquid fuel is generally of petroleum fuel, and represented by diesel, bunker fuel oils (A, B and C) and kerosene. Since bunker fuel oil contains sulfur, the combustion gas usually contains 0.1 to 0.25% SO_2 and further 1 to 5% of such SO_2 is converted into SO_3, causing corrosion.

D) Heating value

a. Solid and liquid fuel

When carbon, hydrogen, sulfur, oxygen, moisture and nitrogen contents in 1 kg fuel are represented by c, h, s, o and w (kg) respectively,

Higher heating value, $Hh = 8{,}100\, c + 34{,}500\, (h - o/8) + 2{,}500\, s$ kcal/kg

Lower heating value, $Hl = Hh - 600\, (9\, h + w)$ kcal/kg

b. Heating value of gaseous fuel

When combustible components contained in 1 m^3 fuel for example, CH_4 and H_2 are represented by ch_4 and h_2 (m^{3}N) respectively,

$$\text{Higher heating value, } Hh = 3{,}055 \cdot co + 3{,}036 \cdot h_2 + 9{,}498 \cdot ch_4 + 14{,}982 \cdot c_2h_2 + 35{,}702 \cdot c_6h_6 \ \text{kcal/m}^3\text{N}$$

$$\text{Lower heating value, } Hl = Hh - 600 \left(\frac{18}{22.4}\right) (h_2 + 2\, ch_4 + 2\, c_2h_4 + c_2h_2 + 3\, c_6h_6) \ \text{kcal/m}^3\text{N}$$

E) Air ratio and volume of combustion gas

Ratio of Aa, actual volume of air used for combustion to Ao, volume of theoretical combustion air (Aa/Ao) is called air ratio (m) and is represented by the following equation:

$$m = \frac{21\,(N_2)}{21\,(N_2) - 79\,[(O_2) - 0.5\,(CO)]}$$

where (CO), (O_2) and (N_2) indicate in Vol.% CO, O_2 and N_2 contained in dry combustion gas respectively.

Fig. III-5-4 to Fig. III-5-6 show relations between heating values against solid, liquid and gaseous fuel at various air ratios and volume of combustion gas.

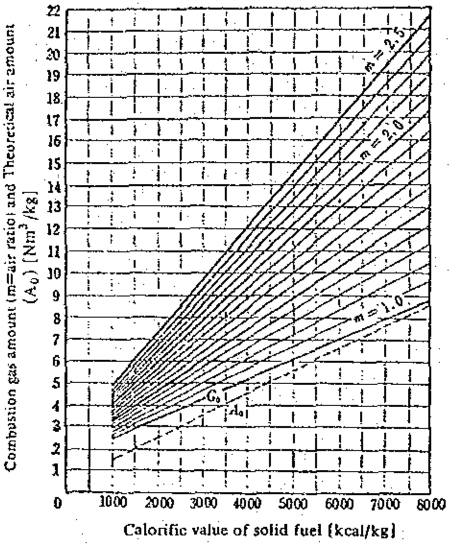


Fig. III–5–4
Relation between low calorific value of solid fuel and combustion gas amount, and theoretical air amount

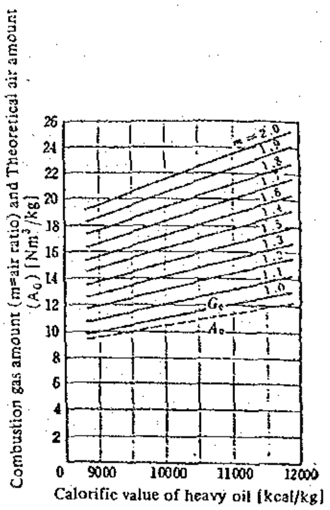


Fig. III–5–5
Relation between low calorific value of liquid fuel and combustion gas amount, and theoretical air amount

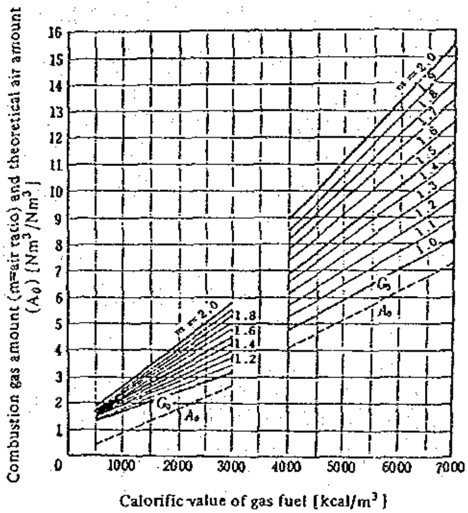


Fig. III–5–6 Relation between low calorific value of gas fuel and combustion gas amount, and theoretical air amount

(2) Heat Balance and Thermal Efficiency

Heat balance is prepared to make an important guide-line on a basis of which the degree of rationalization in the use of energy is judged, through investigation of the heat energy provided to the combustion equipment and of its state of use in order to clarify the relation between heat input and output.

To calculate the heat balance,

(1) Properties of the used fuel
(2) Fuel consumption
(3) Temperature of air
(4) Composition of combustion products
(5) Temperature of flue gas

(6) Amount and temperature of heated matters

(7) Amount and composition of unburnt matters

(8) Chemical reaction in heated matters, etc. on a basis of which the following calculations are made:

- Heat input

  Heat capacity retained by fuel

  $(Q \times F) + (F \times Cpf \times \Delta t)$

  Sensible heat of air

  $V \times Cpv \times \Delta t$

  Heat capacity carried in by heated matters

  $M \times Cpm \times \Delta t$

  Heat input due to chemical changes

  $H \times M$

- Heat output

  Heat capacity carried out by heated matters

  $W \times Cpw \times \Delta t$

  Heat capacity carried out by combustion exhaust gas

  $(E \times Cpe \times \Delta t) + (S \times Cps \times \Delta t) + 600\ S$ (when based on higher heating value)

  Heat loss capacity due to incomplete combustion

$$[E \times \frac{(CO)}{100} \times 3{,}050 \times F] + [8{,}100 \times (\text{amount of soot})]$$

  Heat loss due to unburnt matters in combustion residue

$$F \times 8{,}100 \times \frac{an}{1 - n}$$

  Heat loss due to radiation, conduction, etc.

  $\Sigma(h_c + h_r)(\Delta t)(A)$

  For h_c, refer to item "Basic Calculation of Heat Transfer" as mentioned later.

  $h_r = 4.88\,[(T_o/100)^4 - (T_a/100)^4] \times \epsilon/\Delta_t$

$$\text{or } \frac{\lambda(T_i - T_o)}{l} \cdot A$$

Clarifying the heat balance in combustion equipment will tell how much of the given heat capacity is used for the heating for which it is intended and how much is lost. How much of any given total heat capacity is effectively used is expressed by "Thermal Efficiency": that against total heat input capacity is overall thermal efficiency against total heat input capacity; and that against fuel heating value is overall thermal efficiency against fuel heating value. Since thermal efficiency varies depending on which item is regarded as effective heat capacity, it is necessary to define the effective heating value of each combustion equipment beforehand.

(Symbols)

F: Fuel consumption [kg/h]
Q: Fuel heating value [kcal/kg]
H: Heat of reaction [kcal/kg]

M: Amount of heated matters (input) [kg/h]
W: Amount of heated matters (output) [kg/h]
E: Amount of dry exhaust gas [m^3/h]
S: Amount of steam in exhaust gas [kg/h]
A: Radiating area [m^2]
V: Amount of air [m^3/h]
T_i, T_o, T_a: Furnace temperature, furnace external wall temperature, ambient temperature [K]
Δt: Temperature difference with ambient temperature [°C]
l: Thickness of furnace wall [m]
C_p: Specific heat at constant pressure and the subscripts of f, v, m, w, e, and s indicate a value of fuel, air, heated matters (input), heated matters (output), dry exhaust gas, steam vapor in exhaust gas respectively.
(CO): Vol.% of CO in exhaust gas
h_r: Radiation heat transfer coefficient [kcal/m^2h°C]
h_c: Convection heat transfer coefficient [kcal/m^2h°C]
λ: Thermal conductivity of furnace wall material [kcal/mh°C]
a: Ash content in 1 kg fuel [kg]
n: Carbon content in 1 kg combustion residue [kg]
ϵ: Emissivity of wall surface

(3) Burner

A) Oil Burner

a. Special features of combustion

Special features of oil combustion are:

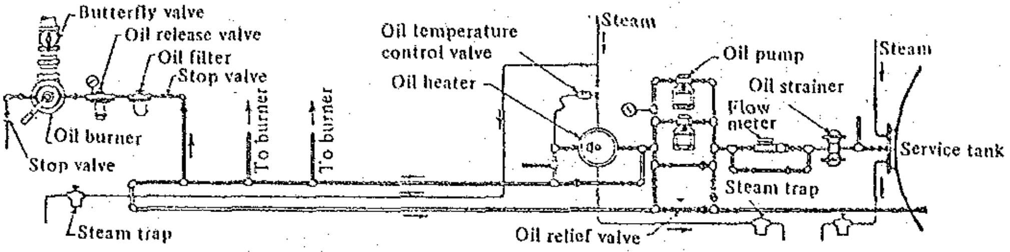
(1) Fuel is uniform in quality and easy to store, transport and handle.
(2) Easy complete combustion and little soot occurs.
(3) High thermal efficiency and high temperature is available.
(4) Easy ignition, extinction and easy control in combustion.
(5) Great capability for fluctuation in load.

On the contrary, the defects are:

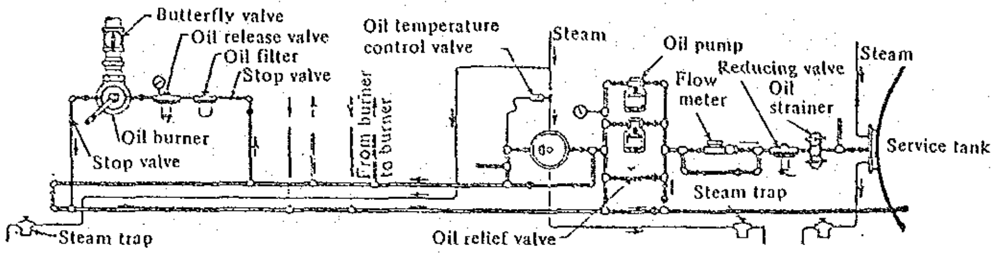
(1) High combustion temperature tends to damage the furnace material.
(2) Some types of burners generate noise.

b. Construction of oil combustion equipment

To completely burn the fuel oil, a storage tank, service tank, oil filter, oil heater, oil pump, oil release valve, etc. are required in addition to an oil burner and layout of their auxiliary equipment is shown in Fig. III-5-7 (a) and (b).



(a) Main return piping system (for large quantities of heavy oil combustion)



(b) Burner return piping system (when the return pipe line has low flow resistance in combustion of heavy oil)

Fig. III–5–7 Combination of oil combustion equipment

c. Selection of oil burner

Classification, special features and applications, etc. of oil burners are shown in Table III-5-1.

As regards selection of oil burner,

(1) Since the characteristics vary according to the type, select a suitable one in respects of heating conditions, type of fuel, construction of the furnace, etc.

(2) When there is a fluctuation in load, take into consideration the oil flow adjusting range.

(3) The burner capacity should be suitable for the heating load capacity.

(4) For automatic combustion, take into consideration the relation with the type of burner.

d. Control of combustion

It is important for burner combustion to keep the oil atomization in good condition. Improper atomization may be caused by intermittent atomization due to sludge, water or other impurities in the fuel, fluctuation in oil pressure, inadequate amount of air or steam for atomization, insufficient oil preheating, etc. Improper atomization makes flame unstable, causing incomplete combustion and carbon to stick to the furnace wall. In addition, feeding method and amount of air for combustion change considerably the state of flame; an excessive feed tends to make a short flame and too little feed, a long one. Adequate air ratio is generally 1.1 to 1.2.

Before ignition of the burner, it is necessary to purge all combustible gas remaining in the furnace and gas flue by fully opening the fire hole and stack damper. After ignition, continue to monitor the flame until the furnace temperature rises, adjust the air ratio and check for complete combustion. To extinguish fire, first stop supply of fuel and try to prevent damage due to rapid cooling of the furnace by closing the fire hole and damper.

Table III–5–1 Properties and applications of various oil burners

	Medium and low pressure air current spray type burner	High pressure air current spray type burner	Horizontal rotary burner	Hydraulic burner	Special burner
Atomizing method	Atomizes by medium or low pressure air or steam.	Atomizes by high pressure air or steam.	Atomizes by means of centrifugal force of a rotator.	Atomizes by pressurizing fuel oil itself.	Atomizes by combination of pressurizing fuel oil itself and use of high and medium pressure air current.
Hydraulic pressure, air or steam pressure	Hydraulic pressure 0.2 to 0.5 kg/cm² Air or steam pressure 200 to 1,550 mm water column	Hydraulic pressure 0.2 to 0.5 kg/cm² Air or steam pressure 2 to 7 kg/cm²	Natural flow down system Hydraulic pressure 0.2 to 0.5 kg/cm²	Hydraulic pressure 5 to 20 kg/cm² For special use, 60 to 70 kg/cm²	Hydraulic pressure 5 to 30 kg/cm² air or steam pressure 0.3 to 5 kg/cm²
Viscosity of fuel oil	Good atomizing even for fuel oil with high viscosity. Atomized air amount to be 30% or less of theoretical air amount.	Viscosity of fuel oil may be higher. Air or steam for atomizing to be 0.5 to 2.0 kg per kg of fuel. 0.4 to 0.7 kg for higher performance.	Kerosene or gas oil with less viscosity Suitable for heavy oil A and B.	Fuel oil with higher viscosity will provide inferior atomizing.	Suitable for kerosene and gas oil with low viscosity and heavy oil A.
Oil amount adjusting range	1 : 5	1 : 10	1 : 5	1 : 1.5 (Non-return system) 1 : 3.0 (Return system)	1 : 3
Spray angle	30 ~ 60°	About 30°	40 ~ 80°	40 ~ 90°	
Characteristic	Blower is low-cost and generally used.	Generates noise.	Less equipment cost and easier handling.	Less operating cost and suitable for large capacity. Ignition must be stabilized.	High in both hydraulic and pneumatic pressures, high equipment cost and generates noise. Good combustion and short flame.
Applications	For heating furnaces, boilers with medium and small capacity.	General heating furnaces, boilers with medium and smal capacity and large boilers (high pressure).	For medium and small boilers.	For boilers with large capacity, for rotary kilns.	For special purposes with medium and small capacity.

B) Gas Burner

a. Special features of combustion

Special features of gaseous combustion are:

(1) Easy adjustment in combustion

(2) Complete combustion is possible even in a cooled combustion chamber.

(3) Less air ratio is needed than for coal and fuel oil and it is easy to adjust atmosphere in the furnace.

(4) Since premixed combustion is possible, high load combustion can be made.

(5) Neither carbon nor ash accumulate in the combustion chamber, burner and

heated matters. Also, the exhaust gas is clean.

On the other hand, the defects are:

(1) For large-capacity, storage and piping equipment are expensive.

(2) It has a smaller flame radiation than liquid fuel.

(3) Gas leakage is difficult to detect and precautions must be taken against explosion.

b. Construction of gaseous combustion equipment

Gaseous combustion equipment does not need as many auxiliary equipments as liquid combustion equipment, but a mixer and burner suffice. Gas burners are mainly divided into two types; one is a diffusion combustion burner, and the other is a premixed combustion burner. The premixed combustion burner needs an injector-mixer to mix fuel gas with air. The injector-mixer has three types; aspiration type with fuel gas, aspiration type with air, and pressure mixing type.

c. Selection of gas burner

Special features of the diffusion combustion burner are:

(1) There is no possibility of flash back and damage to the burner occurring.

(2) Flame is stable even with low grade gas.

(3) Luminance of flame can be intensified.

(4) Air and gas can be preheated higher than the ignition temperature.

Special features of the premixed combustion burner are:

(1) Easy complete combustion

(2) Great space heat load factor

(3) Easy air/gas ratio adjustment

This type of burner uses either an injector-mixer or a ratio control valve to keep the mixture ratio of fuel gas to air constant.

Since there are many types of fuel gas for industrial purposes and many types of burners, to meet each type of fuel gas, are sold on the market, a suitable burner in respect to type and pressure of gas, construction of the furnace, heating method, etc. must be selected. Typical types and special features are shown in Table III-5-2.

d. Control of combustion

When handling the gaseous combustion equipment, special attention should be paid to explosion and intoxication due to CO. Since explosion accidents of combustion equipment tend to occur during ignition for start-up, full attention should be given to purging before ignition and flash back. Also, when there is a periodic turbulence in flame, it is necessary to extinguish the fire once and inspect.

(4) Rationalization in the Use of Thermal Energy in Combustion Equipment

Table III–5–2 Classification and special features of Gas burners

Diffuse combustion gas burner				Premixed combustion gas burner					
Ring gas burner	Pipe gas burner	Torch gas burner	Tile gas burner	Low pressure velocity gas burner	High pressure velocity gas burner	Tunnel gas burner	Flame retention gas burner	Webster gas burner	Variable flame gas burner
Consists of 1 to 3 ring-like paner heads, each of which is controlled by each cock. Good combustion and wide adjusting range.	It is a straight line burner and is controlled by cock like the ring burner. Good combustion and wide adjusting range.	It is a combination of Venturi mixer and flame retention chip burner in which good combustion is made in atmosphere.	Consists of Venturi mixer, burner nozzle and burner tile and the secondary air hole is sufficiently large to provide enough air with small draft.	Type in which combustion gas is sucked in with low pressure air. To increase and decrease the capacity, air/fuel ratio can be accurately and proportionately adjusted only by controlling air pressure. Wide combustion adjusting range. Suitable when adjusting burners individually.	Type in which air is sucked in by fuel gas. To increase and decrease the capacity, air/fuel ratio can be accurately and proportionately adjusted only by controlling fuel gas pressure. Wide combustion adjusting range. Suitable when adjusting burners individually.	One inspilater and one or several burners are jointly used. Narrow adjusting range.	One set of inspilater and one or several burners are jointly used to burn through burner tile released to atmosphere, whereby any optional flame is obtainable.	With the air/fuel ratio constant, the combustion capacity is adjusted by means of a valve. Consists of Venturi throat and flame retention nozzle.	With the combustion capacity and air/fuel ratio constant, it is possible to adjust from sharp short flame to soft long flame.
Gas pressure 75~300 mmaq Combustion capacity 9300~130000 kcal/hr	Gas pressure 75~300 mmaq Combustion capacity 4000~110000 kcal/hr	Gas pressure 75~300 mmaq Combustion capacity 4400~120000 kcal/hr	Gas pressure 75~750 mmaq Combustion capacity 28000~250000 kcal/hr	Gas pressure 50~150 mmaq Air pressure 600~1200 mmaq Combustion capacity 5000~700000 kcal/hr	Gas pressure 700~25000 mmaq Combination capacity 14000~220000 kcal/hr	Combination with low pressure inspilater 5300~1800000 kcal/hr Combination with high pressure inspilater. 9000~330000 kcal/hr	Combination with low pressure inspilater 8000~1400000 kcal/hr Combination with high pressure inspilater. 13000~320000 kcal/hr	Gas pressure 700~14000 mmaq Combustion capacity 100000~3300000 kcal/hr	Gas pressure 250 mmaq Air pressure 250 mmaq Combustion Capacity 17000~1350000 kcal/hr

A) Reduction in Air Ratio

Heat carried out by combustion exhaust gas in the equipment heat balance is greatly influenced by the volume of exhaust gas as mentioned in item (2), which is directly related to the air ratio. Heat loss due to the exhaust gas increases in a straight line with increase in the air ratio as shown in Fig. III-5-8 and Fig. III-5-9. Therefore,

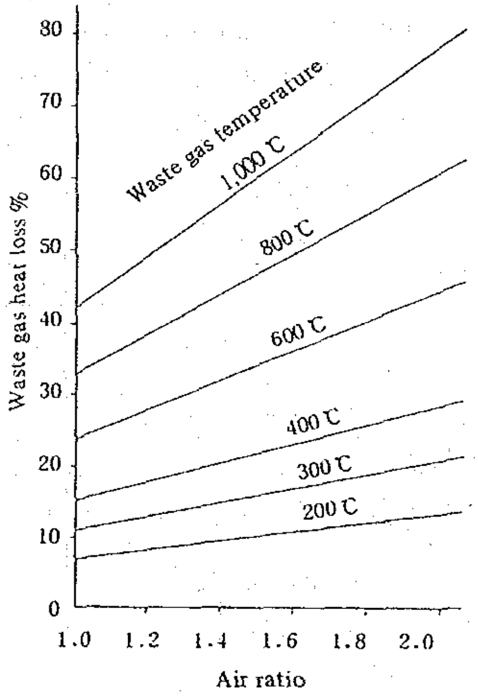


Fig. III–5–8
Relation between air ratio and waste gas loss

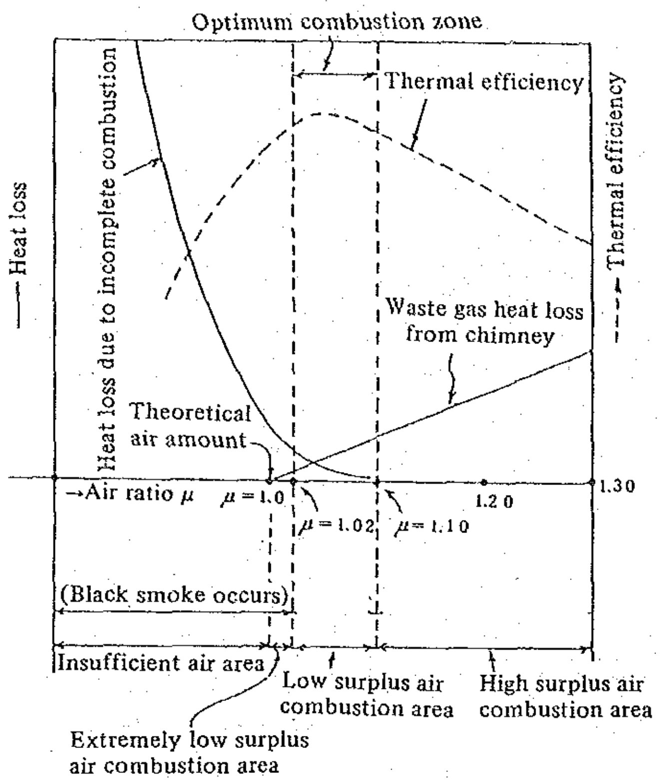


Fig. III–5–9
Relation between air ratio and thermal efficiency

the less the air ratio is, the less heat loss ought to be. Since, however, heat loss due to incomplete combustion takes place when the air ratio is less than 1.1, the maximum value for thermal efficiency exists while the air ratio is between 1.02 and 1.10 (Fig. III-5-9) However, at the general combustion equipment, the load usually fluctuates and, at that time, incomplete combustion may generate black smoke due to a low air ratio. Therefore, the equipment should be, in fact, operated at an air ratio of approximately 1.3, including some allowance. (Table III-5-3)

Table III–5–3

Classification	Standard air ratio
Melting furnace for metal casting	1.3
Continuous billet furnace	1.25
Other metal furnaces than continuous billet furnaces	1.3
Continuous heat treating furnace	1.3
Gas producer and gas heating furnace	1.4
Petroleum heating furnace	1.4
Thermal decomposition furnace and reforming furnace	1.3
Cement calciner	1.3
Alumina kiln and lime kiln	1.4
Continuous glass melting furnace	1.3

Recently, air and fuel flow rates are individually and directly measured and cross-limit type control by means of a computer is performed so that the specified air ratio is always maintained even during fluctuation in load. Thus, it becomes possible to keep the air ratio at 1.02 to 1.10 at all times, resulting in an high energy conservation effect.

B) Recovery of Waste Heat

When the temperature of exhaust gas at the furnace outlet is 1,000° C even at an air ratio of 1.2, the exhaust gas loss is close to 50%. This indicates that energy conservation of combustion equipment depends on recovery of heat in the exhaust gas.

a. Preheating of raw material

Since raw material is usually charged at normal temperatures, a preheating chamber is provided at the material charging place and exhaust gas is introduced here to heat the raw material. Suspension preheater systems in cement plants are a good example of this method. (Fig. III-5-10)

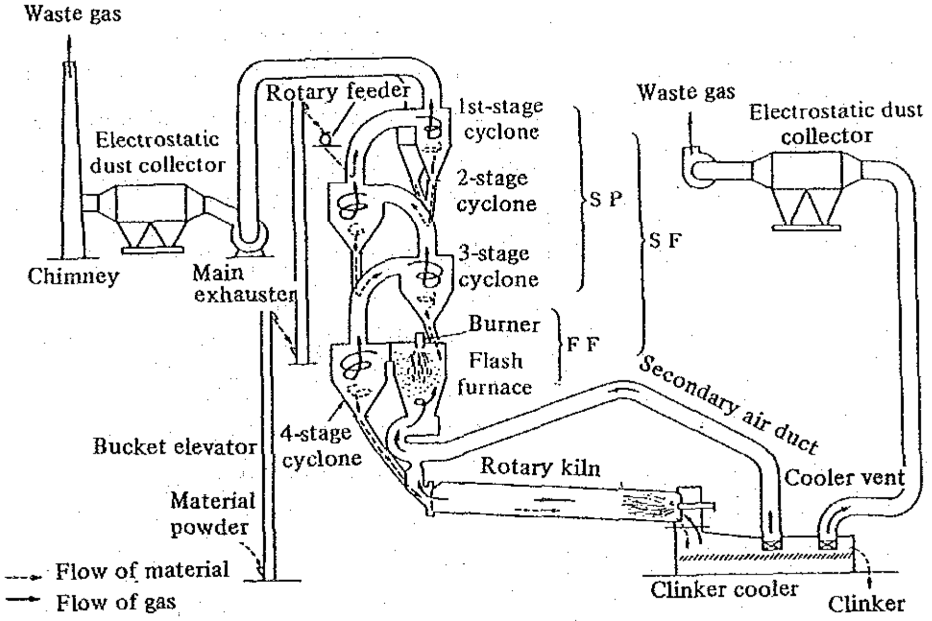


Fig. III–5–10 New suspension preheater system cement plant

b. Preheating of combustion air

When temperature of combustion air is raised by the use of a heat exchanger, the used amount of fuel will decrease as can be seen from the heat balance equation. As one example, air preheating temperature and fuel economy rate at air ratio of 1.3 are shown in Fig. III-5-11. Attention here should be paid to corrosion due to sulfur

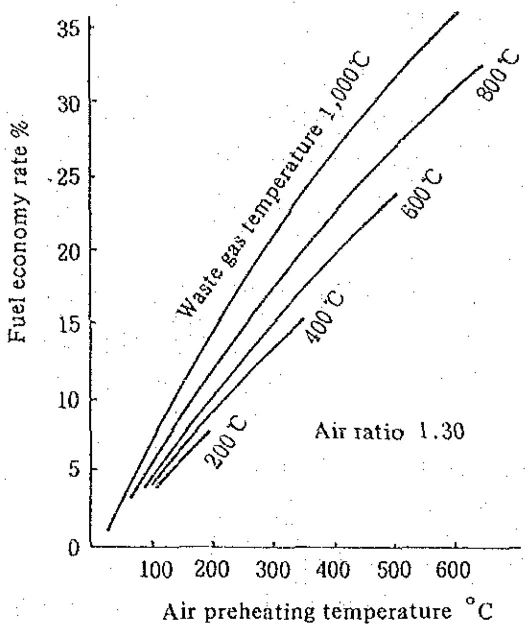


Fig. III–5–11 Fuel economy due to air preheating

contained in fuel. Sulfur is in the form of SO_2 in the exhaust gas, and a portion of such SO_2 is converted into SO_3. SO_3 further combines with water vapor in the combustion gas into sulfuric acid vapor, which reaches the dew point at low temperature walls to liquefy, corroding the heat exchanger. The dew point temperature is difficult to clarify theoretically and determined empirically. It is generally said to be 110 to 160 °C for fuel oil combustion. (Refer to item for Boiler in a later section.)

c. Utilization as other heating source

If sensible heat of the exhaust gas is suitable in heat capacity, temperature range, etc. for heating source of other equipment and it is located near the other equipment, the utilization should be considered. Also, if there is a demand for steam in the factory, it is advisable to install a waste heat boiler and utilize sensible heat of the exhaust gas for steam generation.

C) Utilization of Sensible Heat of Heated Matters

Heated matters from combustion equipment are at high temperature, and as such they, except as subsequently treated in the next process, generally are cooled to ambient temperature or mostly quenched to prevent side reaction. In such a case, the sensible heat of heated matters should be recovered for effective utilization. Good examples are utilization of clinker cooling air as primary combustion air in cement plants (Fig. III-5-10) and waste heat boiler for quenching gas at cracker outlet in ethylene plants, etc.

4.1.2 Heat Transfer Equipment

(1) Basic Calculation of Heat Transfer

When there is a temperature difference between two objects, movement of heat (heat transfer) occurs, a mechanism of which is classified into the following three:

- Heat transfer by conduction
- Heat transfer by convection
- Heat transfer by radiation

Since heat transfer practically occurs under mechanism of combination of these three, it will be extremely complicated if precise calculations are made. However, the calculations can be, in most cases, simplified by the use of approximation or simplification of phenomena. Equations under the respective mechanism are described below:

A) Heat transfer by conduction

When the temperature at each portion does not vary according to time, namely, under a steady state, it is described.

a. In the case of plane

When n sheets of plates lie one upon another, heat flow, Q transferring through these plates is:

$$Q = A_o \cdot \Delta t / \sum_{j=1}^{n} (l_j/\lambda_j) \qquad \text{(kcal/h)}$$

Where A_o: Area of a surface perpendicular to the direction of heat transfer (m^2)

Δt: Temperature difference between low and high temperature (°C)

l: Thickness of plate (m)

λ: Heat conductivity of plate (kcal/mh°C)

Assuming $\Sigma(l_j/\lambda_j) = R$, R may be called heat resistance.

b. In the case of cylindrical surface

Using the same symbols as item a.

$$Q = 2\pi \cdot \Delta t \cdot L / \sum_{j=1}^{n} \left[\frac{1}{\lambda_j} \cdot l_n(r_{j+1}/r_j)\right] \qquad \text{(kcal/h)}$$

Where L : length of cylinder (m)

r_j, r_{j+1}: Inside and outside diameters of jth layer (from inside) (m)

B) Heat transfer by convection

This involves various conditions such as specification of fluid, flow condition, shape of object, aspect of change in fluid phase, etc., for each of which theoretical equations and experiments are individually made. Frequently used representative ones are described herein.

a. Mean heat transfer coefficient, αm in natural convection when the fluid is air.

i) In the case of plate

Convection from lower surface

$$\alpha m = 1.13\,(\Delta t/l)^{1/4} \quad (\text{kcal/m}^2\text{h°C}) \qquad 3 \times 10^5 < Gr \cdot Pr < 3 \times 10^{10}$$

Note: Refer to Table III-5-4

Where Δt: Temperature difference (°C)

l: Representative length of plane (m)

Gr: Grashof number

Pr: Prandtl number

Convection from upper surface

$\alpha_m = 2.27\,(\Delta t/l)^{1/4}$ (kcal/m^{2}h °C) $10^5 < Gr \cdot Pr < 2 \times 10^7$

$\alpha_m = 0.831\,(\Delta t)^{1/3}$ (kcal/m^{2}h °C) $2 \times 10^7 < Gr \cdot Pr < 3 \times 10^{10}$

Convection from vertical surface

$\alpha m = 1.22\,(\Delta t/H)^{1/4}$ (kcal/m^{2}h °C) $10^4 < Gr \cdot Pr < 10^9$

$\alpha m = 1.13\,(\Delta t)^{1/3}$ (kcal/m^{2}h °C) $10^9 < Gr \cdot Pr < 10^{12}$

Where H: Height of vertical surface

ii) In the case of horizontal pipe

$\alpha m = 1.14\,(\Delta t/D)^{1/4}$ (kcal/m^{2}h °C) $10^4 < Gr \cdot Pr < 10^9$

$\alpha m = 1.07\,(\Delta t)^{1/3}$ (kcal/m^{2}h °C) $10^9 < Gr \cdot Pr < 10^{12}$

$\alpha m = 0.4\,(\lambda/D)$ (When D is small) (kcal/m^{2}h °C)

$G_r \cdot P_r < 10^{-5}$

Where D : Outside diameter of pipe (m)

Table III–5–4 Dimensionless terms related to heat transfer

Name	Equation	Abbreviation
Nusselt number	hD/k	Nu, N_{Nu}
Stanton number	h/CpG	St, $N_{St} = (Nu)(Re)(Pr)$
Condensation number	$h(\nu^2/g)^{1/3}/k$	Co, N_{Co}
Reynolds number	DG/μ, $D\bar{u}/\nu$	Re, N_{Re}
Prandtl number	$Cp\mu/k$	Pr, N_{Pr}
Péclet number	$CpDG/k$	$Pé$, $N_{Pé} = (Re)(Pr)$
Grashof number	$(D^3g/\nu^2)(\beta\Delta t)$	Gr, N_{Gr}
Graetz number	wCp/kl	Gz, $N_{Gz} = \frac{\pi}{4}(Re)(Pr)(D/l)$

Note: D^3g/ν^2 is referred to as Galilei number.

$D^3g/\nu^2 = (Re)^2/(\bar{u}^2/gD)$, $\bar{u}^2/gD$ are referred to as Froude number.

C_p : Specific heat at constant pressure

D : Diameter or representative length

Δt : Temperature difference

$G = \bar{u}\rho$: Mass velocity

$\bar{u}$: Average velocity of flow

$w = \frac{\pi}{4} D^2 G$: Mass flow

g : Gravitational acceleration

k : Heat conductivity

μ : Viscosity ρ : Density $\nu = \mu/\rho$: Kinetic viscosity

β : Coefficient of thermal expansion l : Tube length

b. Heat transfer coefficient, α in forced convection

i) Inside heat transfer coefficient

$\alpha D/\alpha = 0.027(Re)^{0.8}(Pr)^{1/3}(\eta/\eta_w)^{0.14}$

Where D: Inside diameter of pipe (m)

η: Viscosity of fluid

η_w: Viscosity of fluid at tube wall temperature

ii) Outside heat transfer coefficient

$\alpha D/\alpha = C \cdot (Re)^m \times 1.11 \cdot (Pr)^{0.31}$

Where D : Outside diameter of pipe (m)

C and m vary according to values of Re, as follows:

Re	C	m
4×10^{-1} to 4	0.891	0.330
4 to 4×10	0.821	0.385
4×10 to 4×10^3	0.615	0.466
4×10^3 to 4×10^4	0.174	0.618
4×10^4 to 4×10^5	0.0239	0.805

C) Heat transfer by radiation

Heat flux, Q radiated around from an object at a temperature of T (K) is represented by the following equation:

$Q = 4.88\,\epsilon \cdot A \cdot (T/100)^4$ (kcal/h)

Where ϵ: Emissivity of object

A: Surface area of object (m^2)

Heat flux, Q transferred between two objects at different temperatures (1, 2) is represented by the following equation:

$$Q = A_1 F_{12} \frac{4.88}{\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right)} \left[(T_1/100)^4 - (T_2/100)^4\right] \quad \text{(kcal/h)}$$

Where A_1: Radiation area of object 1 (m^2)

F_{12}: Coefficient determined by relative position of object (View factor)

T_1, T_2: Respective temperatures (K)

ϵ_1, ϵ_2: Respective emissivity

Radiation heat to wide space can be approximated by the use of the equation in item (ii) in the following equation:

$Q = A.\ 4.88.\ \epsilon[(T_1/100)^4 - (T_0/100)^4]$ (kcal/h)

Where T_1, T_0: Temperatures (K) of object and ambient respectively

D) Calculation example of heat transfer composed of three modes of heat transfer

Taking the case of heat transfer from lower plane surface equipment to atmosphere, it is described.

Heat flow, Q = Conduction heat transfer through equipment wall Q_k = Convection heat transfer Q_c + radiation heat transfer Q_r .... (1)

Treating temperatures within the equipment, on its surface and of atmosphere as

t_i (°C), t_w (°C) and t_o (°C) respectively,

$$Q_k = A \cdot (t_i - t_w) / \sum_{j=1}^{n} (l_i / \lambda_i) \quad \cdots\cdots (2)$$

$$Q_c = 1.13 \left(\frac{t_w - t_o}{l}\right)^{1/4} \cdot A \cdot (t_w - t_o) \quad \cdots\cdots (3)$$

$$Q_r = 4.88 \cdot \epsilon \left[\left(\frac{t_w + 273}{100}\right)^4 - \left(\frac{t_o + 273}{100}\right)^4 \right] \cdot A \quad \cdots\cdots (4)$$

If t_w is determined by solving the equation which is obtained by substituting equations (2) to (4) for equation (1), the heat flow can be calculated. Since this equation is complicated, we usually cannot help but resort to iconography or the method of trial and error for the solution. However, it is needless to say that it can be easily solved by means of a computer.

(2) Heat Transfer Calculation of Heat Exchanger

A) Overall heat transfer coefficient

Heat transfer through wall of single tube is expressed by overall heat transfer coefficient, U_o based on the outside diameter in the following equation, combining heat resistance of the tube wall and dirt resistance thereto and inside and outside convection heat transfer.

$$1/U_o = (1/h_i)(D_i/D_o) + 1/h_o + (x/\lambda)(D_o/D_m) + R_i(D_i/D_o) + R_o$$

Where h_i: Inside tube convection heat transfer coefficient

h_o: Outside tube convection heat transfer coefficient

D_i: Inside diameter of tube

D_o: Outside diameter of tube

D_m: Mean diameter of tube

x: Thickness of tube wall

λ: Heat conductivity of tube wall

R_i: Inside dirt resistance

R_o: Outside dirt resistance

Since the dirt resistance depends on quality of fluid, temperature, fluid velocity, and the degree of cleaning, it is difficult to discuss generally. For reference, an example of various dirt resistance is shown in Table III-5-5. Value R will not decrease to zero even if the heat exchanger is completely cleaned, and heat transfer is greatly influenced by the degree and frequency of cleaning. Therefore, maintenance of the heat exchanger has a great influence on energy conservation.

In multitubular heat exchangers, the overall heat transfer coefficient calculated as a single tube cannot be used as-is, but there is another equation with somewhat modification and also correction is required.

The correction is determined by the layout of tubes, the number of arrangements, the flow direction, etc. and is complicated. Here, the description is omitted and actual examples are shown in Table III-5-6.

Table III–5–5

(a) Scale coefficient of water

Temperature of high temperature fluid (°C)	Up to 115		115~205	
Water temperature (°C)	52 or below		52 or above	
Velocity of flow of water (m/sec)	1 or below	1 or above	1 or below	1 or above
Sea water	0.0001	0.0001	0.0002	0.0002
Service water, well water, cooling tower water, large lake, engine jacket, softened boiler feed water	0.0002	0.0002	0.0004	0.0004
Distilled water	0.0001	0.0001	0.0001	0.0001
Hard water (15 grains/gal or more)	0.0006	0.0006	0.001	0.001
River water (average)	0.0006	0.0004	0.0008	0.0006

(b) Scale coefficient of various fluids

Oil		Gas, vapor		Liquid	
Fuel oil	0.001	Organic matter vapor	0.0001	Organic matter liquid Refrigerant liquid Brine (for cooling)	0.0002
Machine oil	0.0002	Steam (containing no oil)	0.0001		
Transformer oil		Alcohol vapor			
Clean circulating oil		Steam (containing oil)	0.0002		
Quenching oil	0.0008	Refrigerant vapor	0.0004		
Vegetable oil	0.0006	Air			

Table III–5–6 Overall coefficient of heat transfer of multi-tube heat exchangers

Service condition	High temperature fluid	Low temperature fluid	Overall coefficient of heat transfer (kcal/m²·hr·°C)
Cooler	Water	Water	1,200~2,500^{*1}
	Methanol	〃	1,200~2,500^{*1}
	Ammonia	〃	1,200~2,500^{*1}
	Water solution	〃	1,200~2,500^{*1}
	Organic matter viscosity 0.5cP or below^{*4}	〃	350~ 750
	Organic matter viscosity 0.5~1.0cP^{*5}	〃	250~ 600
	Organic matter viscosity 1.0cP or below^{*6}	〃	25~ 400^{*2}
	Gas	〃	16~ 250^{*3}
	Water	Brine	500~1,000
	Organic matter viscosity 0.5cP or below^{*4}	Brine	200~ 500
Heater	Steam	Water	1,000~3,500^{*1}
	〃	Methanol	1,000~3,500^{*1}
	〃	Ammonia	1,000~3,500^{*1}
	〃	Water solution viscosity 2.0cP or below	1,000~3,500
	〃	Water solution viscosity 2.0cP or above	500~2,500^{*1}
	〃	Organic matter viscosity 0.5cP or below	500~1,000
	〃	Organic matter viscosity 0.5~1.0cP^{*5}	250~ 500
	〃	Organic matter viscosity 1.0cP or above	30~ 300
	〃	Gas	25~ 250^{*3}
Heat exchanger	Water	Water	1,200~2,500^{*1}
	Water solution	Water solution	1,200~2,500^{*1}
	Organic matter viscosity 0.5cP or below^{*4}	Organic matter viscosity 0.5cP or below^{*4}	200~ 400
	Organic matter viscosity 0.5~1.0cP^{*5}	Organic matter viscosity 0.5~1.0cP^{*3}	100~ 300
	Organic matter viscosity 1.0cP or above^{*6}	Organic matter viscosity 1.0cP or above^{*6}	50~ 200
	Organic matter viscosity 1.0cP or above^{*6}	Organic matter viscosity 0.5cP or below^{*4}	150~ 300
	Organic matter viscosity 0.5cP or below^{*4}	Organic matter viscosity 1.0cP or above^{*6}	50~ 200

Note 1: Overall coefficient of heat transfer shown on the above table are, with the exception of *1, *2 and *3, based on when the scale coefficient and the allowable pressure loss on the controlling fluid side are assumed to be 0.006 m²·hr·°C/kcal and 0.35 to 0.7 kg/cm² respectively.

Note 2: *1 to *6 on the above table are as follows:

*1. When scale coefficient is 0.0002 m²·hr·°C/kcal.

*2. When pressure loss is 1.4 to 2.1 kg/cm².

*3. Greatly varies with service pressure of the gas.

*4. Organic matters such as benzene, toluene, acetone, ethanol, methyl ethyl ketone, gasoline, light kerosene, naphtha, etc.

*5. Organic matters such as kerosene, hot gas oil, heat absorber oil, a portion of crude oil, etc.

*6. Organic matters such as chilled gas oil, fuel oil, crude oil, tar, asphalt, etc.

B) Mean temperature difference

Heat transfered, Q in heat exchanger is expressed by the following equation:

$Q = A_o \cdot U_o \cdot \Delta t_m$ .... (1)

Where A_o: Heating surface based on outside tube

Δtm: Mean temperature difference between both fluids

The temperature difference between both fluids, Δt, may in most cases, differ according to each spot in the heat exchanger. In both high and low temperature fluids as for one passage type heat exchange, when a differential equation for heat balance with A_o and Δt as variables is solved,

$Q = A_o \cdot U_o \cdot (\Delta t_1 - \Delta t_2)/l_2(\Delta t_1/\Delta t_2)$ .... (2)

The above equation is obtained.

Where subscripts of Δt show inlet and outlet of the heat exchanger respectively.

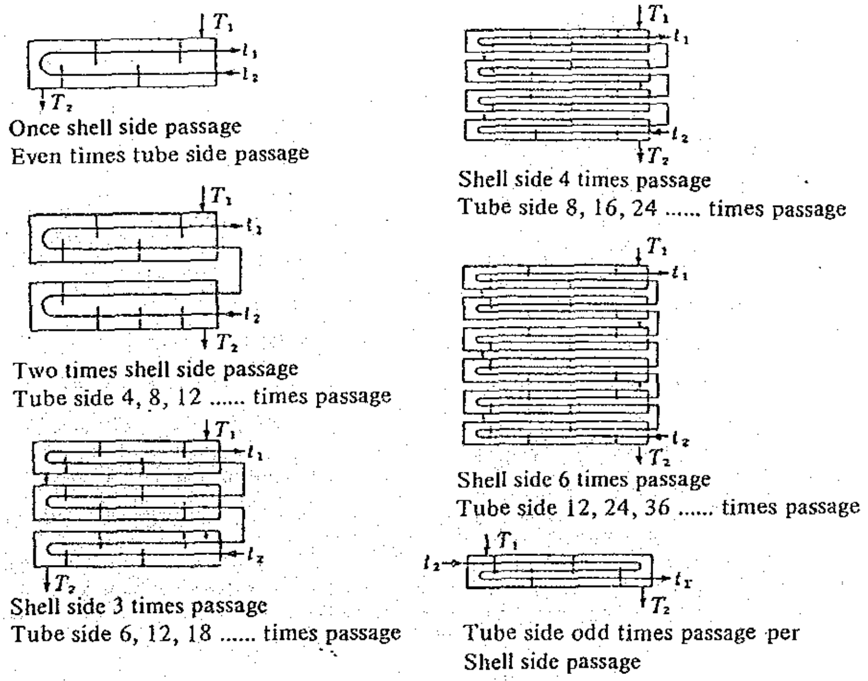
Equispacing equations (1) and (2),

$\Delta t_m = (\Delta t_1 - \Delta t_2)/l_n(\Delta t_1/\Delta t_2)$ .... (3)

This is called logarithmic mean temperature difference. In many of the heat exchangers in practical use, the fluid channel is complicated as shown in Fig. III-5-12, and, as such, the temperature difference value calculated from equation (3) cannot be used as-is but needs some correction. Treating the correction factor as F_t, mean temperature difference Δt_m is calculated by the following equation:

$\Delta t_m = F_t \cdot (\Delta t_1 - \Delta t_2)/l_n(\Delta t_1/\Delta t_2)$ .... (4)

Values F_t due to each channel configuration are shown in Fig. III-5-13 (a) to (f).



Once shell side passage
Even times tube side passage

Two times shell side passage
Tube side 4, 8, 12 ...... times passage

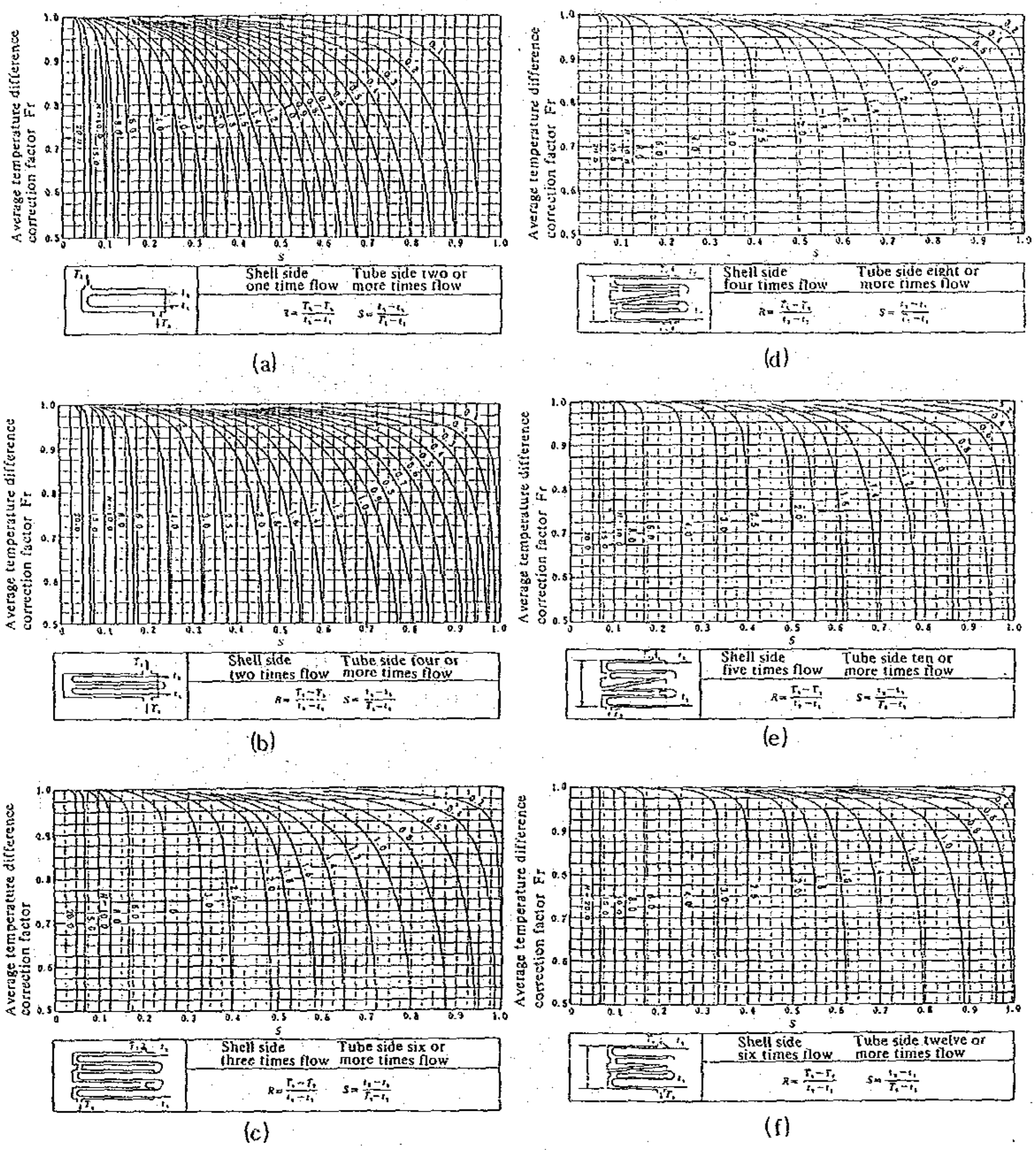
Shell side 3 times passage
Tube side 6, 12, 18 ...... times passage

Shell side 4 times passage
Tube side 8, 16, 24 ...... times passage

Shell side 6 times passage
Tube side 12, 24, 36 ...... times passage

Tube side odd times passage per
Shell side passage

Fig. III–5–12 Shell/Tube type heat exchanger



(a) (d)

(b) (e)

(c) (f)

Fig. III−5−13 Correction factor Fr

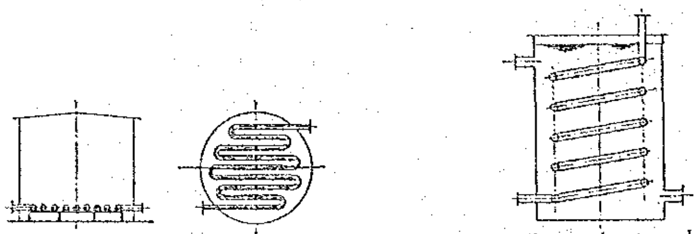
(3) Types of Heat Exchangers

Heat exchangers are mainly divided according to type of heat transfer element from the constructional standpoint and further classified according to the type of container to house the heat transfer element. They are divided from the constructional standpoint as follows:

A) Tubular type (Fig.III-5-14 ~ Fig.III-5-17)

- a. Coil type heat exchanger
- b. Trombone type (Cooler)
- c. Double tube type heat exchanger
- d. Multitubular heat exchanger
  - (1) Fixed tube and plate type
  - (2) Floating head type

(3) U-tube type



(a) Tank heater (b) Coil type heat exchanger

Fig. III-5-14

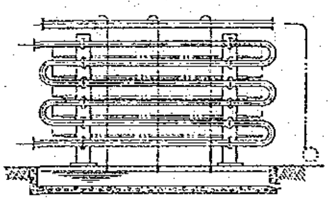


Fig. III-5-15 Trombone cooler

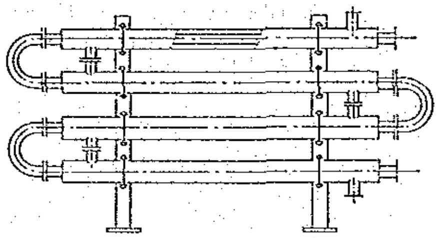
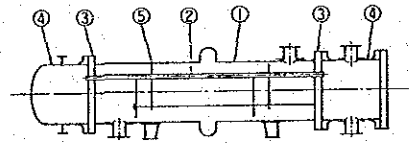
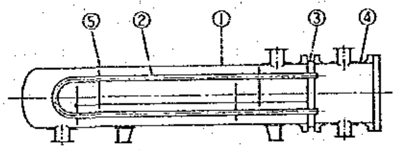


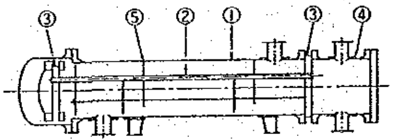
Fig. III-5-16
Double tube type heat exchanger



(a) Fixed tube sheet type heat exchanger



(b) U-tube type heat exchanger



(c) Floating head type heat exchanger
(1) Shell (2) Heating tube (3) Tube plate
(4) Partition chamber (5) Baffle

Fig. III-5-17 Multi-tube type heat exchanger

B) Plate type (Fig. III-5-18 ~ Fig. III-5-19)

a. Jacket type heat exchanger

b. Plate type heat exchanger

c. Spiral type heat exchanger

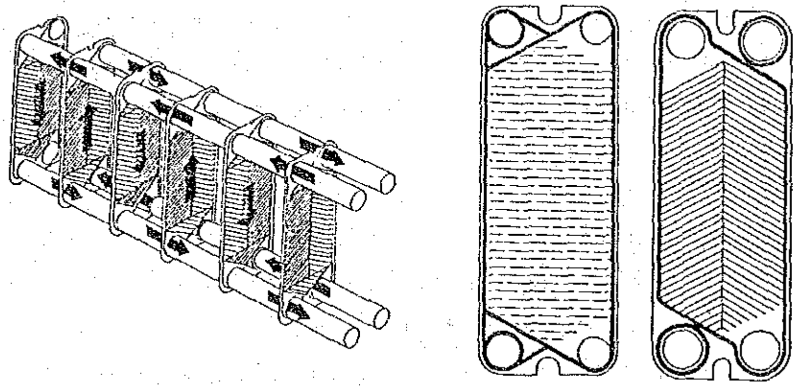


Fig. III–5–18 Plate type heat exchanger

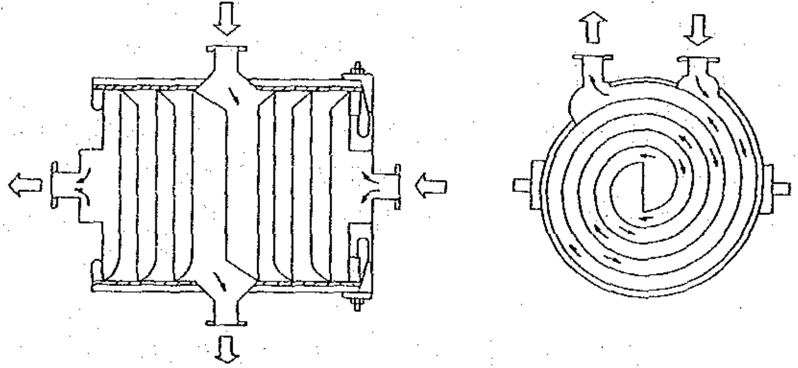


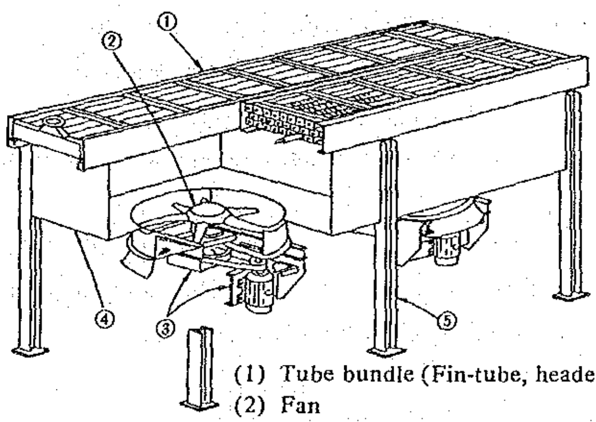
Fig. III–5–19 Spiral type heat exchanger

C) Special type (Fig. III-5-20)

a. Air cooling type heat exchanger

b. Bayonet heat exchanger

c. Compact heat exchanger



(1) Tube bundle (Fin-tube, header)
(2) Fan
(3) Drive
(4) Plenum chamber
(5) Frame

Fig. III–5–20 Air cooling type heat exchanger

Characteristics of typical ones of the above-mentioned heat exchangers are described.

Coil type heat exchangers:

Many of coil type heat exchangers are installed within storage tanks and reactors, etc. The overall heat transfer coefficient is greatly affected by the outside tube heat transfer coefficient. The construction is simple, the cost is low, and cleaning and replacement are generally easy. When condensation is expected in the fluid within the tube in design, consideration must be given not to prevent condensate from discharging.

Trombone type cooler:

Since Trombone type coolers consist of 180° bends and straight tubes, replacement of tubes and extension works are easy. Also, since there is little possibility of leakage, they are used for special processes such as a cooler for sulfuric acid and for fluid cooling. Since the water side heating surface often contacts with air, aerobic plants are liable to breed and scale tends to stick due to water evaporation. Therefore, do not neglect cleaning.

Double tube type heat exchangers:

Double tube type heat exchangers are used for small-scale type with heating surface to the extent of 15 to 20 m^2. Care should be taken in the cleaning of the annular space between the inside and outside tubes, and leakage from the gland jointed portion.

Multitubular heat exchangers:

Multitubular heat exchangers are most widely used in chemical industries, have high reliability in practical use, and can be designed and manufactured to a wide variety of specifications for high temperature and high pressure to large capacities. The fixed tube and plate type is low-cost and easy to manufacture, but the shell side fluid must be restricted to non-corrosive little contaminated material. Floating head type has advantages that it is easy to inspect and clean the heating tubes because the tube bundle can be drawn outside, and that no thermal stress is generated because thermal expansion due to the temperature difference in the fluid is absorbed. However, it is complicated in construction and expensive.

U-tube type has no possibility of thermal stress, and its tube bundle can be easily drawn outside for cleaning. However, it has a defect in that it is difficult to clean the bent portion of the tube.

In multitubular heat exchangers, tubes are attached to tube plate by tube expanding work and looseness and corrosion at this portion cause the fluid to leak. Therefore, this spot must be checked for maintenance.

Plate type heat exchangers:

The heating area can be freely increased and decreased by adjusting the number of plates used and it is easy to assemble and clean. Since turbulance can be given to the flow, the heat transfer coefficient is great. However, the use is limitted to a pressure of approximately 10 kg/cm^2 and temperature of approximately 150°C from the constructional standpoint. Many of them are used in pharmaceutic and food processing industries and general chemical industries have begun to use them.

Spiral heat exchangers:

Since the fluid rotates, turbulance increases the heat transfer coefficient. Like the plate type, it is possible to design a small-size type. Flange construction facilitates disassembly. Since, however, the clearance is small, it is difficult to inspect the back between the plates.

Air cooling type heat exchangers:

Air cooling type heat exchangers consist of finned tubes, header, fan and its drive. Since the cooling medium is air, it is convenient when cooling water is dirty or in short supply. To use, consideration should be given to the place for installation so that cool, fresh air may be introduced.

4.2 Unit Equipment in Use for Chemical Plants

4.2.1 Reactors

Reactors are equipment which play a leading part among equipments in chemical industries, and generally occupy an important position also in thermal energy.

Reactors used in various chemical industries vary in a wide range and several different reactors are used even for the same chemical reaction. However, we follow their general classification and describe the respective characteristics:

(1) Classification by construction and form

A) Vessel type reactors

These reactors are most widely used in chemical industries. They are generally equipped with agitator, and jacket and coil, etc. for the heat exchanger. These types are used for both batch and continuous operation over a wide range of temperatures and pressures. They are widely used for the manufacture of alum, citric acid, soap, adhesives, sodium silicate, cupric sulfate, etc.

B) Tubular type reactors

These reactors are installed for both single tube and parallel multitubular type. Mostly, heat exchange is made between inside and outside tube fluids and heat transfer is accelerated when filled with catalyst. They are used for synthesis of ammonia, oxidization of naphthalene, decomposition of hydrocarbons, etc.

C) Tower type reactors

These reactors are of a vertical, cylindrical type with a larger diameter than the tubular type. Some of them are filled with solid packings or catalytic particles, some are equipped with baffles, or some are only empty towers, etc. They are used for the manufacture of formalin, hydro-desulfurization of petroleum distillates, etc.

(2) Classification by temperature control

A) Isothermal operation

Isothermal operation is made when heat of the reaction is small, when reaction mass is very small, or when inert fluid with great heat capacity is introduced, or heat exchange with the outside is so sufficiently performed that it is regarded as almost isothermal within the reactor.

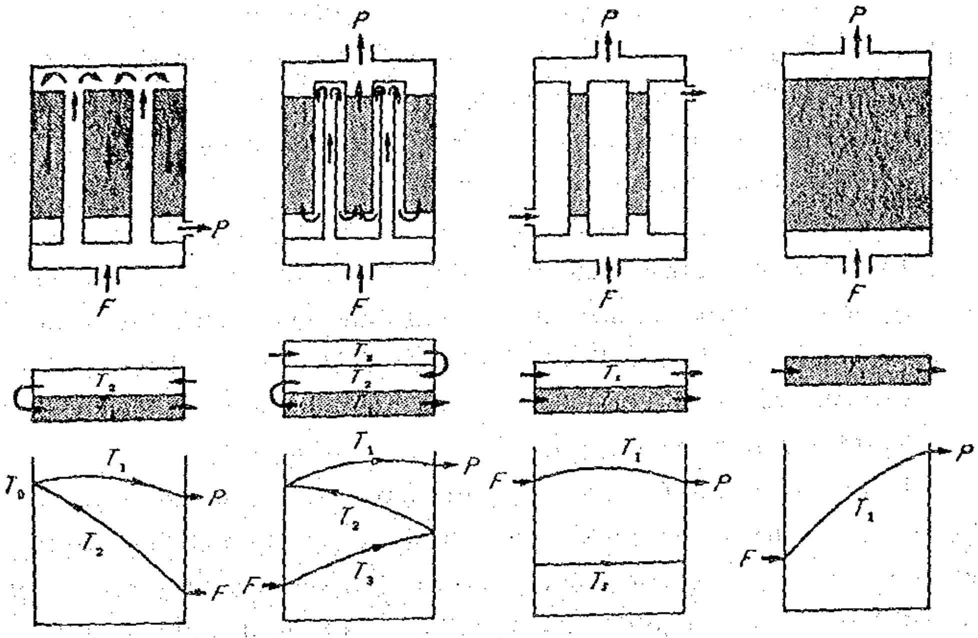
B) Adiabatic operation

Adiabatic operation is made when no heat exchange is performed between the reaction system and the outside, but the reaction is adiabatically performed. In this case, heat of evolution or heat of absorption due to the reaction as-is becomes an increase or decrease in enthalpy of the reaction system.

When heat of the reaction is great, some factories use a method to bring temperature distribution in the reactor close to optimum temperature distribution, in which the reaction layer is divided into several stages, a heat exchanger (or heater or cooler) is inserted between each stage, or reaction fluid at low temperature (or high temperatue) is introduced to adjust temperature at inlet of each adiabatic reaction layer. This is called multiple adiabatic operation and is used for an SO_3 converter in a sulfuric acid plant and ammonia synthesis converter.

C) Heat exchange operation

This operation is widely used to deal with heat of reaction and transfers heat of reaction from reactor wall to outside of the system. This operation is divided into two; self-heat exchange type, and external heat exchange type. In the former type, a reaction fluid itself cools (or heats) the reaction chamber and, at the same time, itself is preheated (or cooled) and enters the reaction chamber. In the latter type, the reaction chamber is cooled or heated by an other heating medium. Concrete examples of the above types are shown in Fig. III-5-21 and Fig. III-5-22.



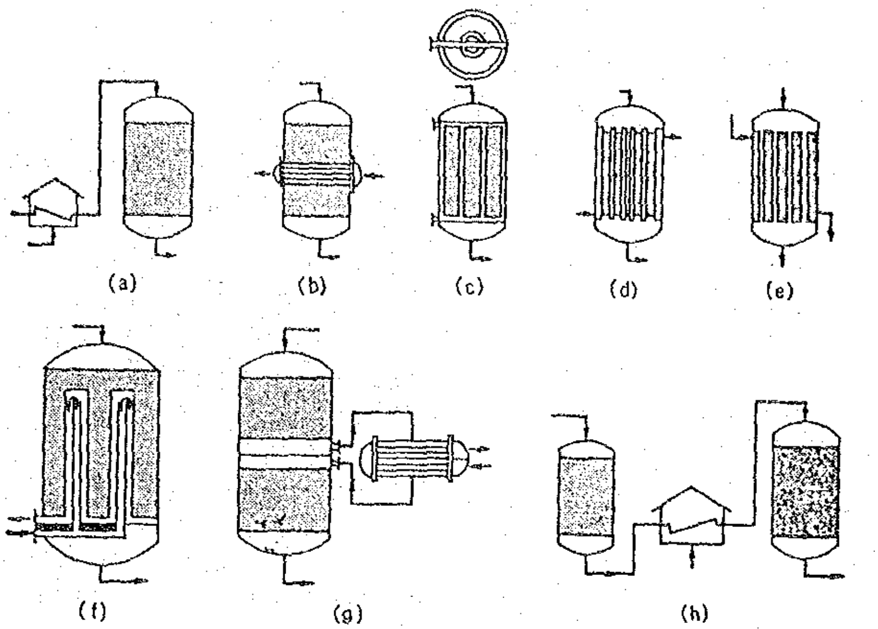
(a-1) Self-heat exchange system

(a-2) External heat exchange system

(a) Heat exchange operation
F: Feed fluid P: Product fluid

(b) Adiabatic operation

Fig. III–5–21 Temperature control method and temperature profile of reactor



(a) Preheating system (b) Internal heat exchange system (c) Ring cooling space system
(d) Packed-in-tubeing system (e) Packed-out-tube system (f) Tube and barrel system
(g) External heat exchanger system (h) Multi-stage system with external heat exchanger

Fig. III–5–22 Heat exchange system of fixed catalytic reactor

(3) Rationalization in the Use of Thermal Energy

Since chemical reactions of industrial purposes generally abound in exothermic reactions, it will be described.

To preheat raw material, heat should be obtained from the heat exchange with high temperature products after reaction or heat exchange within the reactor or in intermediate cooling, etc., and heating with fuel, steam, etc. from the outside of the system should be minimized.

For cooling for temperature control in the intermediate reaction layer or cooling of high temperature products at the reactor outlet, together with or separately from the preheating method, it is desirable to effectively recover the heat of reaction and utilize it both outside and inside of the system by the following methods:

a. Heating of boiler feed water or steam generation.
b. Heating of air or of other fluids.

[Enforcement example 1]

In a sulfuric acid plant using sulfur as raw material shown in Fig. III-5-23, heat of evolution from the sulfur burner is utilized for steam generation, and the heat of reaction in an SO_3 converter is utilized for preheating of raw material air in the intermediate cooling and for preheating of feed water in cooling at outlet. As a result, 1 ton of high pressure steam is generated per ton of 100% sulfuric acid. (An example in the U.S.A.)

[Enforcement example 2]

In a reactor to manufacture formalin by air oxidizing methanol, heat of reaction is recovered as low pressure steam by quenching product gas at a temperature of 600 to 630° C after reaction at a quenching boiler. The amount of recovered steam is about

400 kg per ton of 38% formalin and all steam is consumed in the plant. The amount of steam supplied from the outside of the system is only about 100 kg. (An example in Japan.)

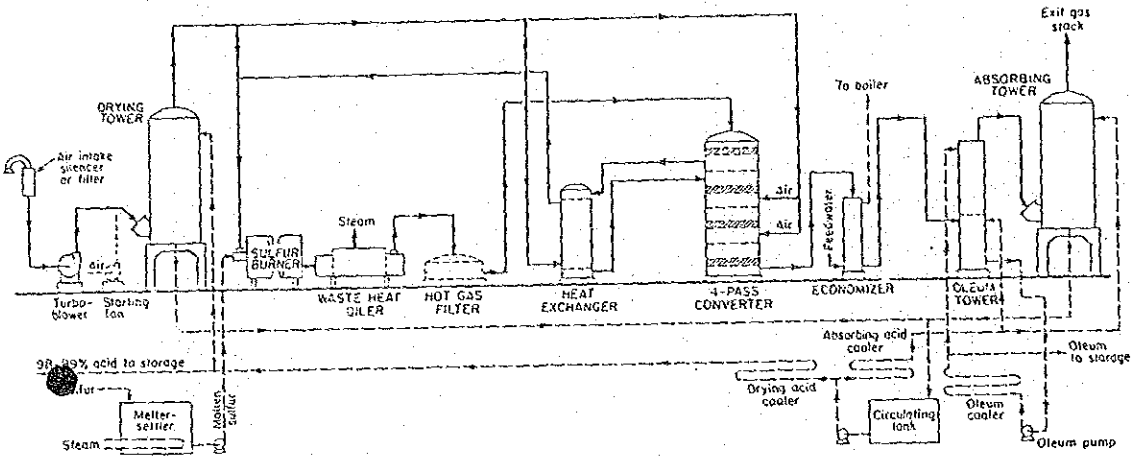


Fig. III–5–23 Typical flowchart for a sulfure-burning contact sulfuric acid plant

4.2.2 Distilling Plants

(1) Principle of Distillation

When a mixed solution consisting of two or more volatile matters is evaporated, the vapor is richer in components of low boiling-point than the original solution, while the remaining liquid is more concentrated with components of high boiling-point. Applying this principle, it is the distillation operation that separates the solution at higher concentrations in a specified component from the mixed solution. Distilling plants used for this purpose are widely adopted in chemical plants.

Moreover, when vapor once generated is condensed and it is evaporated again, the low-boiling point component in the vapor is more concentrated and the remaining liquid will be increasingly rich in high-boiling point component on the same principle. This principle is materialized into a multi-stage distillation tower. In the multi-stage distillation tower, vapor generated from one plate comes into direct contact with liquid on the upper plate and condenses, in which case the latent heat is released. This latent heat is further used for evaporation of liquid on the said plate. Since such a phenomenon occurs throughout all plates in the tower, the thermal energy required for the distillation is usually sufficed with only heat input to the bottom heater; cooling for condensation of vapor is sufficed by only the overhead condenser. Next, peculiar factors to the multi-stage distillation operation are described:

<Reflux>

To keep the composition of the overhead product constant (in the case of continuous operation), or to improve separation from the high-boiling point component (for both batch and continuous operation), a portion of the overhead distillate is returned to the top, which is reflux. Ratio (Flow rate of reflux)/(Flow rate of overhead product) is called "Reflux ratio" and one of very significant factors in the distillation operation.

<Relation between reflux ratio and number of plates of towers>

Relation between a number of plates (called "Theoretical number of plate"), N required to separate product at a specified concentration from original solution and the reflux ratio, R is shown in Fig. III-5-24.

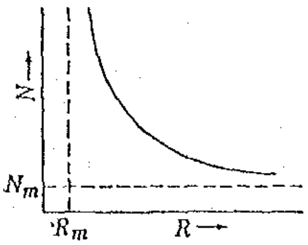


Fig. III–5–24

R cannot be made less than R_m, but the required plate number of the tower will be infinite when R is equal to R_m. Also, when R is increased, the required number of plates will decrease. Even if R is infinite, the plate number cannot be decreased less than N_m. R_m and N_m are called minimum reflux ratio and theoretical minimum number of plates respectively, each of which is one of the important factor for design and operation of a distilling plant.

<Relation between reflux ratio and thermal energy>

Vapor flow rate which rises in a tower is the same at any plate in the tower, unless there is cooling or heat release in the tower, and such amount is (1 + R) × (Flow rate of overhead product) × (Latent heat of evaporation), being provided by the bottom heater.* Accordingly, reduction in R directly leads to energy conservation in a distilling plant.

*Note: This is when the feed being charged is at its boiling point and in any other cases, correction in a thermal state of the feed is necessary.

(2) Classification of Distillation Towers

A) Plate tower

Plates used to hold liquid in the tower are provided in multi-stages, and the plates themselves are turned into perforated plates or many bubble caps are provided in order to make the contact between vapor rising from a lower plate and liquid on the plates better. Also, various devices are provided to collect a specified amount of liquid on each plate and to allow the liquid to flow down smoothly to a lower plate.

B) Packed tower

Packings which are of shapes to perform gas-liquid contact efficiently are packed in a tower to perform evaporation and condensation continuously instead of stepwise. Although this tower is inferior to A) in performance as a distillation tower, it has advantages in that the equipment is low-cost and the pressure drop in the tower is less. However, packings with better performance than the plate tower are recently sold on the market, though expensive.

(3) Rationalization in the Use of Energy

A) Optimization of Reflux Ratio

Although reduction in R leads to energy conservation as mentioned above, increase in the high-boiling point component in the overhead product and increase in the low-boiling point component in the bottom product occur, resulting in lowered performance of separation in the distilling plant.

In general, taking into consideration adverse effects which may be caused by fluctuations in feed composition, fluctuations in pressure of heating steam, etc., it is, in most cases, seen that the operation is made at a larger value of R than required with margin. Although R is generally determined empirically, it is advisable to first endeavor to minimize the range of fluctuation in various fluctuating conditions and to determine the lowest value of R which will not affect the product quality, by decreasing R gradually. Also, since value R is influenced by feed plates number, it is also a method to change the feed plates according to a method of trial and error.

B) Cleaning of Plates or Packings

Vapor actually generated from each plate is not in an equilibrium composition with the liquid. Against this deviation, considering a plate efficiency and regarding the quotient obtained by dividing the required plate number theoretically calculated by the plate efficiency as the real plate number, actual equipment is made.

When the plates or packings are contaminated by foreign matters contained in the liquid during operation, the plate efficiency will lower below the design value. Therefore, we cannot help but increase R to maintain the performance. To prevent this, it is important to release the tower periodically and inspect and clean the inside.

C) Recovery of Waste Heat due to Heat Exchanger

Since overhead vapor has latent heat, utilize this for the heater in the tower at low temperatures and preheat feed with sensible heat retained in the bottom product. (See Fig. III-5-25.)

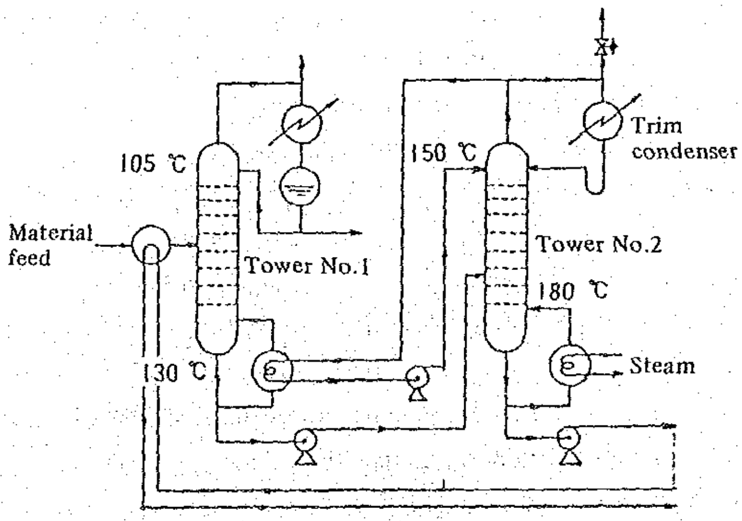


Fig. III-5-25

Also, heat in the overhead condenser can be utilized to generate low pressure steam when the vapor is at high a temperature. (See Fig. III-5-26.)

There is a method to utilize vapor in the overhead product for the bottom heater by pressurizing the vapor to raise the condensation temperature, though it may be a somewhat expensive plant. (See Fig. III-5-27.)

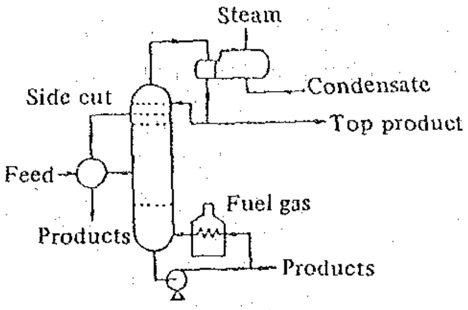


Fig. III-5-26

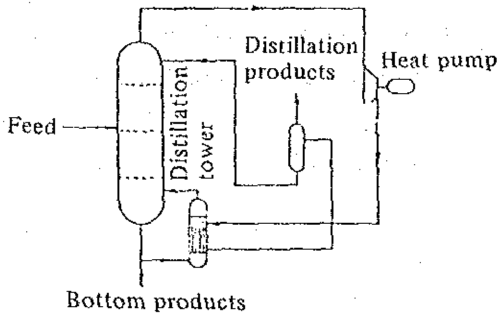


Fig. III-5-27

D) Precautions for Heat Insulation

When the distillation tower proper is not heat insulated, or when it is poorly insulated, heat release from the tower wall will condense a part of rising vapor in the tower (It is called partial condensation.). When partial condensation occurs, reflux ratio, R will decrease at above plates, resulting in lowered separation performance in the distillation tower. If R is going to be maintained to prevent this, it will be necessary to supplement only an amount of heat loss from the tower wall by the bottom heater.

4.2.3 Evaporators

Evaporators are, in most cases, used for concentration and crystallization of solutions in chemical plants. Since solvent for solution is generally water and its latent heat of evaporation is great, evaporators are important equipment as the subject of energy conservation. As heat source, combustion gas, direct flame, electric heat, heating medium, etc. are used in addition to steam, but only steam heating type will be discussed here.

(1) Types of Evaporators

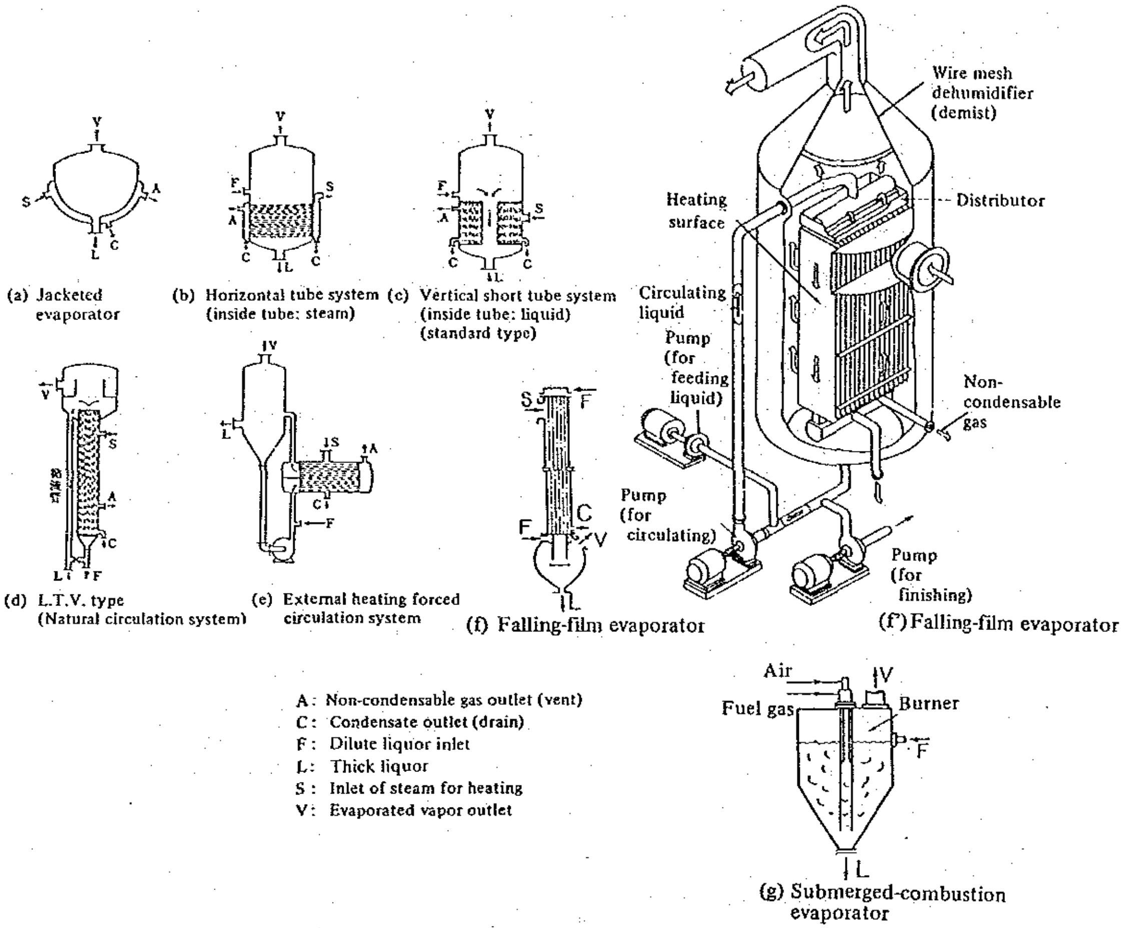
Construction of typical evaporators is shown in Fig. III-5-28.

(a) is often used for batch type.

(b) is low in equipment cost per unit heating area and easy to replace tubes.

In (c), liquid is naturally circulated, being heated while it falls down along a central large tube (called downtake), and rises within small tubes and this type is most widely used. In (d), solution becomes a vapor-liquid mixture in heating tubes and rises at a high rate in jet, and the efficiency is high. In (e), heating and evaporation areas are separated and it is easy to replace and clean tubes and convenient to operate. In (f) and (f'), solution evaporates while it is flowing down in the form of a film on the heating surface, and it is suitable for concentration of the solution with high viscosity and sensitivity to heat. Heat transfer portion has two types: one is vertical, long tube type (f), and the other is plate type (f'). The former is not suitable for solution which forms scale and crystal because of inside tube flow down system.

Uniform distribution of solution on the heating surface is one of the important operating conditions for both types. In (g), evaporation is performed by blowing out hot gas in a liquid, or by installing a burner in the liquid, allowing it to burn directly and blowing out combustion gas at high temperatures in the liquid. Since evaporation is performed by direct liquid-gas contact in the presence of inert gas, concentration is performed at low temperatures, and the heat transfer capacity is great. (g) is used for concentration of highly corrosive solutions such as sodium sulfate, phosphoric acid, dilute sulfuric acid, magnesium chloride, etc.



(a) Jacketed evaporator
(b) Horizontal tube system (inside tube: steam)
(c) Vertical short tube system (inside tube: liquid) (standard type)
(d) L.T.V. type (Natural circulation system)
(e) External heating forced circulation system
(f) Falling-film evaporator
(f') Falling-film evaporator
(g) Submerged-combustion evaporator

A: Non-condensable gas outlet (vent)
C: Condensate outlet (drain)
F: Dilute liquor inlet
L: Thick liquor
S: Inlet of steam for heating
V: Evaporated vapor outlet

Fig. III-5-28 Examples of evaporators

(2) Effective Utilization of Energy

Since evaporation requires a lot of energy, several methods shown in Fig. III-5-29 are adopted with reference to use of steam from an energy economy standpoint.

a. Steam recovery method

Steam is utilized as-is; (a)

Steam is otherwise utilized after compressing it; (b)

b. Steam (re)compression method

Evaporated steam is utilized for heating itself after compressing it; (c), (h), (j)

c. Back pressure utilization method

Utilization of turbine exhaust; (d), (i)

d. Multiple effects method

Discussion later; (e)

e. Combination of above methods

Methods in conjunction with the multiple effects method; (f), (g), (h), (i)

In addition, there is a multi-stage flash evaporation method, which uses heat retained in generated steam to preheat feed solutions, and is applied to desalination of sea water.

(3) Rationalization in the Use of Thermal Energy

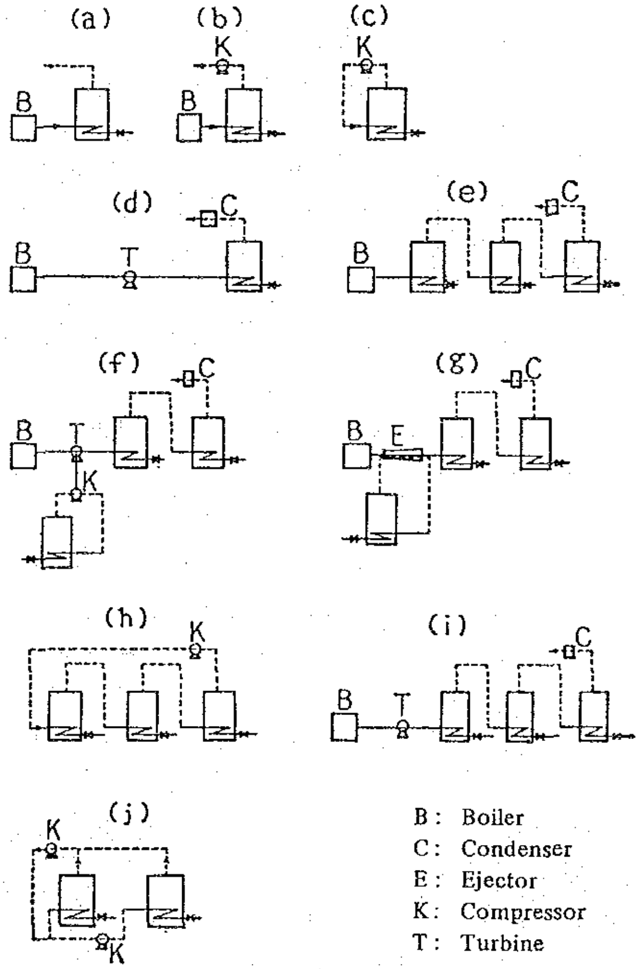
Although energy unit of evaporation largely depends upon the methods mentioned in the preceding item, it is also affected by many other factors, which will be described below:

A) Effect of Scale

If salts which will form scale are contained in solutions, scale deposits on the heating surface, becomes a heat transfer resistance or blocks, because the heating tube wall has the maximum temperature. Therefore, it is advisable to prevent this by the following methods:

a. Remove scale formation ingredients beforehand.

b. Select pH, concentration, temperature, etc. of the liquid.



B : Boiler
C : Condenser
E : Ejector
K : Compressor
T : Turbine

Fig. III–5–29 Classification of evaporation systems

c. Introduce suitable chemicals.

d. Select the type of evaporator to which it is difficult for scale to stick, and to thoroughly clean.

B) Steam Consumption in Steam Ejectors

Steam ejectors are generally used to maintain pressure in evaporators and remove non-condensable gas such as air, etc. Driving steam is usually condensed by a barometric condenser, and the temperature of cooling water used for this condenser is related to an amount of driving steam. That is, the lower the temperature of water is, the less the amount of steam required is and also the lower the pressure of steam may be.

For example, steam pressure of 15 atg is required when water in the barometric condenser is at 41° C, but when the water temperature comes to 35° C, a steam pressure of 10.6 atg will suffice.*

*Note: Representing saturated pressure corresponding to water temperature in the barometric condenser as Pt_1, Pt_2, and ejector driving steam pressure corresponding to each of them as P_1, P_2 respectively,

$$\frac{P_1 + 1.033}{P_2 + 1.033} = \frac{Pt_1}{Pt_2}$$

(Unit) Pt_1, Pt_2: Torr

P_1, P_2 : kg/cm^2G

C) Air Purge in Steam Heating Chamber

When air or other inert gas is contained in heated steam and solutions, the gas accumulates in the heating chamber, heat transfer is impeded, and lowered steam partial pressure lowers heating temperature. As a countermeasure to prevent this, a purge valve is provided in the heating chamber and purging operation is periodically and slightly excessively performed. It is theoretically said that discharge should be continued until the temperature of the discharge gas reaches the temperature in the steam chamber.

It is desirable that the air discharge valve should be located on the exact opposite side to the steam inlet and in the steam flow direction.

(4) Multi-Effect Method

When the boiling point is brought below the temperature of condensation of generated steam in the preceding stage evaporator, by lowering the inside-evaporator pressure on the 2nd stage and after below the pressure in each preceding stage in Fig. III-5-29(e), generated steam in the preceding stage is introduced into the heating chamber in the next stage and its heat of condensation will be utilized for evaporation in the next stage.

It is a special feature of the multi-effect method that remarkably less steam consumption suffices than when a specified evaporation is performed in a single evaporator. When the number of effects (number of stages) is N, the heating steam will be theoretically 1/N of that of a single evaporator and the larger N is, the more advantageous it will be from a thermal economical standpoint. However, the equipment and operation costs will in fact increase with N, there will exist an economically optimum value for N. Briefly assuming that steam cost is in inverse proportion to N and fixed cost is in proportion to N, the optimum number of effect, N_{opt} is expressed by the following equation:

$$N_{opt} = \sqrt{P/K}$$

Where $P = W_y \cdot C_s / F_e$

K: Mean steam economy (Amount of water evaporated by 1kg of steam per evaporator; 0.85 to 0.9)

W_y: Annual amount of evaporation (kg/y)

C_s: Unit price of steam (Bt/kg)

F_e: Fixed cost of evaporator (Bt/y)

4.2.4 Dryers

Dryers which are constructed to evaporate moisture from a wet material by allowing hot air to contact will be discussed here. Since the material to be dried varies in a wide range in shape and physical and chemical properties and its moisture content also differs, the drying operation will vary according to each case. Therefore, many types of dryers to meet respective material characteristics and operations are sold on the market. It is very important to select the equipment. However, this proposal will only give general consideration to problems for material and equipment here and describe general energy conservation of dryers.

(1) Class of Dryers

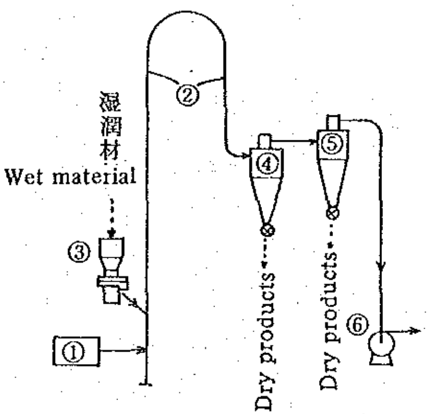
Dryers are classified by the relation between material moving system and heat transfer of the material to be dried, as follows:

A) Hot Air Dryers

a. Hot air conveying types

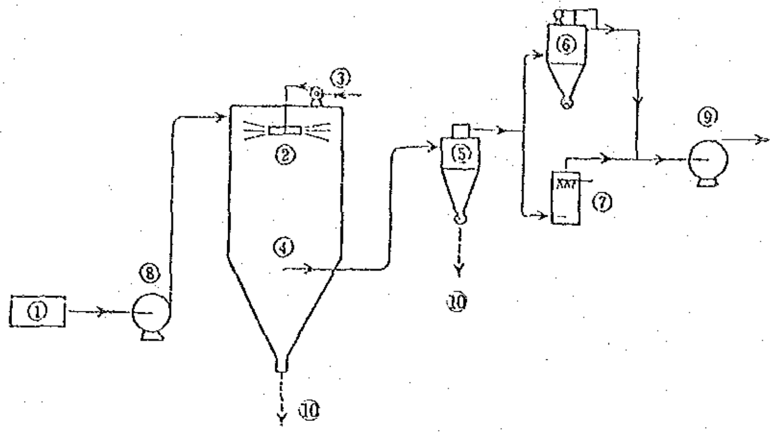
① Flash dryer (See Fig. III-5-30)

② Spray dryer (See Fig. III-5-31)



(1) Hot air producer (2) Drying tube (3) Material feeding device
(4) Primary cyclone collector (5) Secondary cyclone collector
(6) Exhauster

Fig. III–5–30 Distribution diagram of flash dryer (Direct feed system)



① Hot air producer ② Sprayer ③ Feed liquid pump ④ Drying tower proper
⑤ Cyclone collector ⑥ Bag filter ⑦ Scrubber ⑧ Blower ⑨ Exhauster
⑩ Dried products

Fig. III–5–31 Distribution diagram of spray drying

b. Material agitation types

① Rotary dryers

Single cylindrical direct heating type

Double cylindrical direct, indirect heating type

External heating type (See Fig. III-5-32)

② Multiple-stage disk dryer (See Fig. III-5-33)

③ Groove type agitation dryer (See Fig. III-5-34)

④ Fluidized bed dryers

Multi-stage continuous type

Horizontal multi-chamber continuous type

One-stage continuous type (See Fig. III-5-35)

Batch type

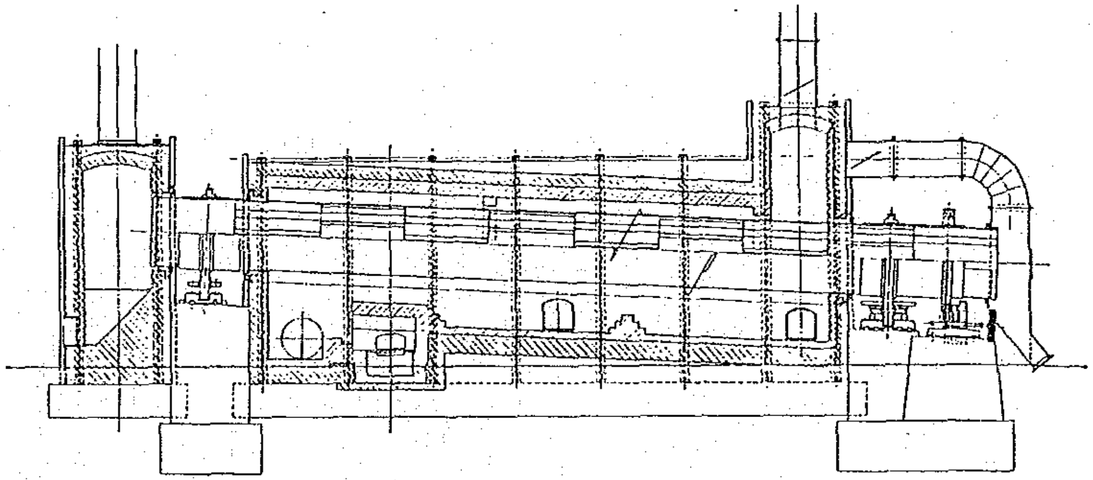


Fig. III–5–32 External fire type rotary dryer

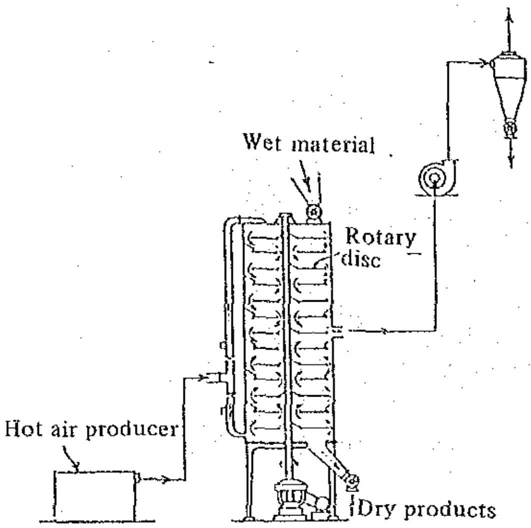
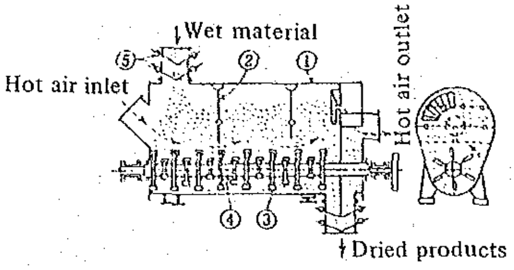
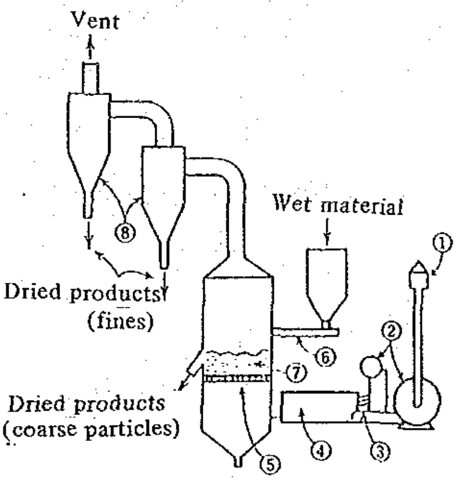


Fig. III–5–33
Multiple-stage disc hot air dryer



① Shell ② Partition plate ③ Agitation blade
④ Agitation shaft ⑤ Weight damper

Fig. III–5–34
Hot air groove type agitation dryer

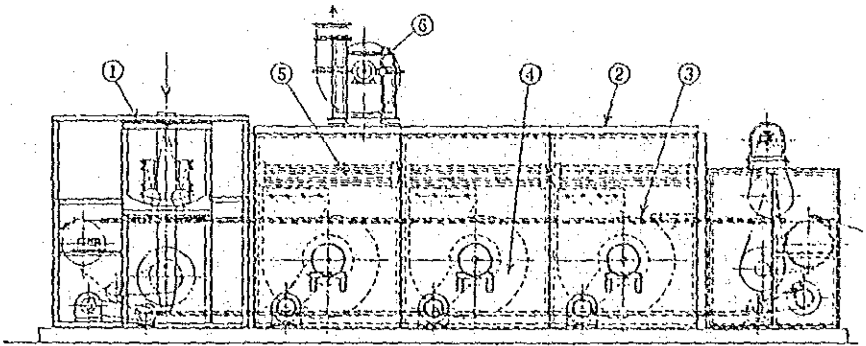


① Air filter ② Blower ③ Burner ④ Air heater ⑤ Distributor
⑥ Material feed device ⑦ Fluidized bed ⑧ Cyclone

Fig. III–5–35 One stage continuous flow dryer

c. Material conveying types and stationary types

① Through-circulation dryers
Band type (See Fig. III-5-36)
Rotary type (See Fig. III-5-37)
Vertical moving bed type (See Fig. III-5-38)
Box batch type (Fig. III-5-39)
② Tunnel dryer (See Fig. III-5-40)
③ Band dryer
④ Box dryer
⑤ Sheet dryer (See Fig. III-5-41)



① Material molding machine ② Drying chamber ③ Conveyor
④ Hot air circulation blower ⑤ Heater ⑥ Exhauster

Fig. III–5–36 Band type continuous through-circulation dryer

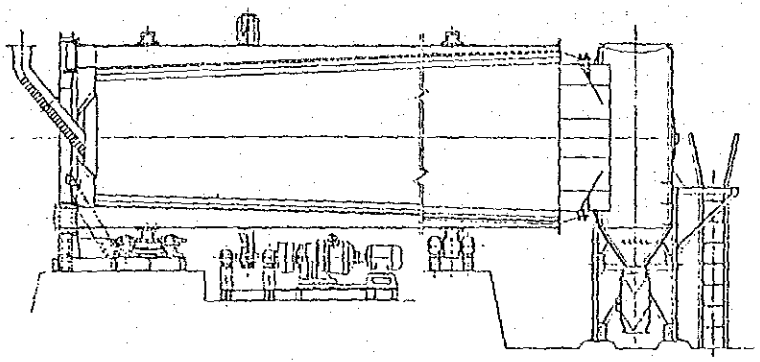


Fig. III–5–37 Rotary type continuous through-circulation dryer

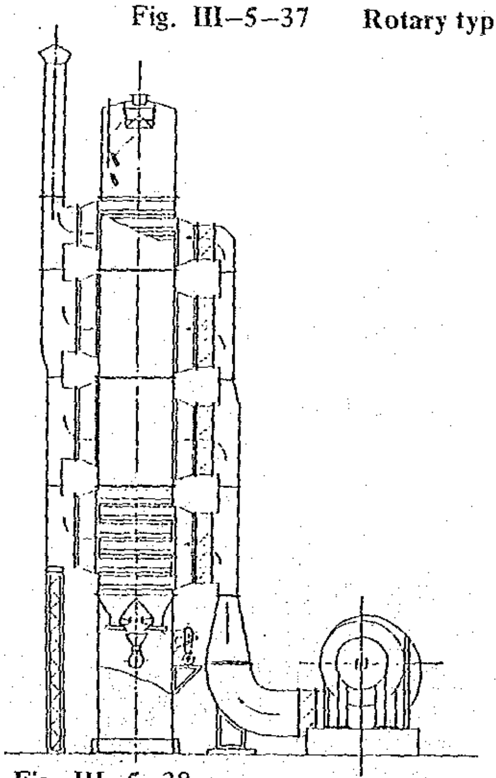


Fig. III–5–38
Vertical type continuous moving bed through-circulation drying system

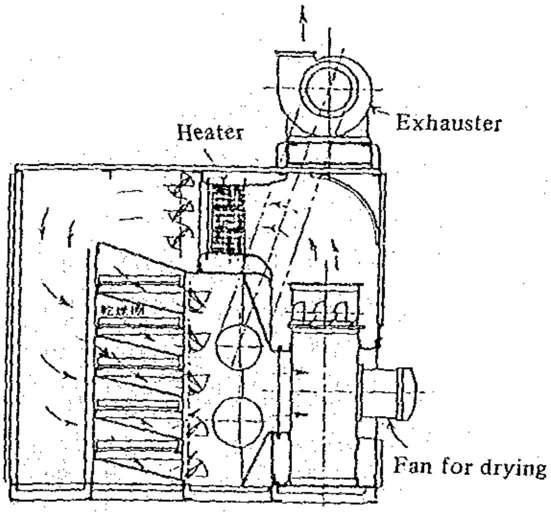


Fig. III–5–39
Box batch type through-circulation dryer

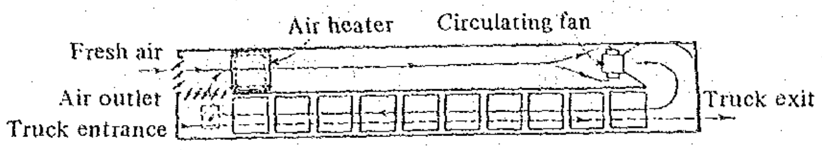


Fig. III–5–40 Distribution diagram of counter-current tunnel dryer

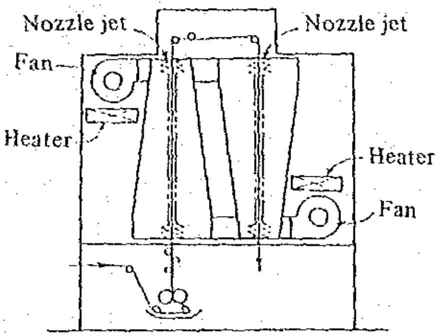


Fig. III–5–41 Vertical nozzle jet dryer

B) Heat Conduction Dryers

a. Material agitation types

① Groove type agitation dryer

② Cylindrical agitation dryers

Atmospheric pressure type, Vacuum type

③ Plate agitation dryer

④ Rotary dryer with steam heating tubes (See Fig. III-5-42)

⑤ Multi-stage agitation dryer (See Fig. III-5-43)

⑥ Vacuum rotary dryer

b. Material stationary types

① Vacuum dryer (See Fig. III-5-44)

② Freezing dryer (Fig. III-5-45)

c. Cylindrical types

① Drum dryers

Atmospheric pressure type (See Fig. III-5-46 and Fig. III-5-47), Vacuum type

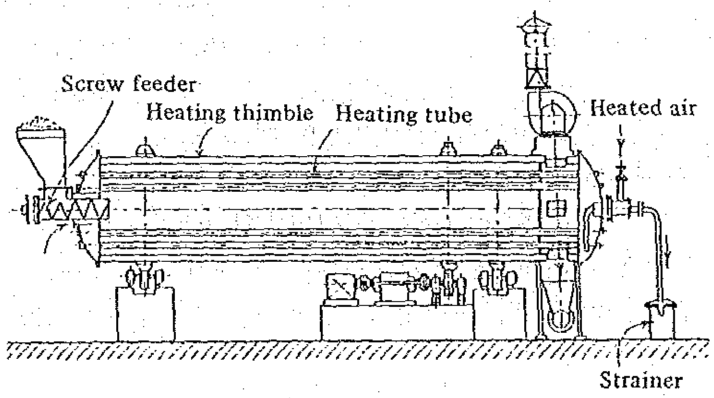


Fig. III–5–42 Rotary dryer with steam heating tube

② Cylindrical dryer

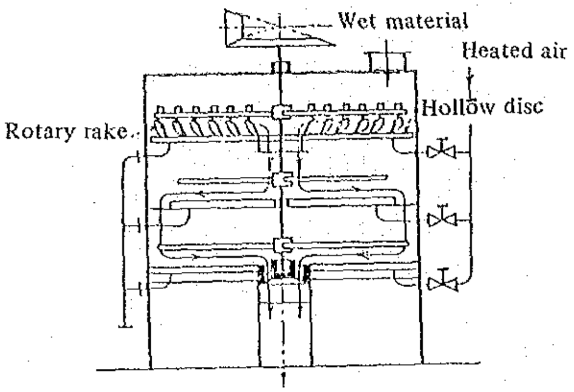


Fig. III–5–43
Multiple-stage agitation indirect dryer

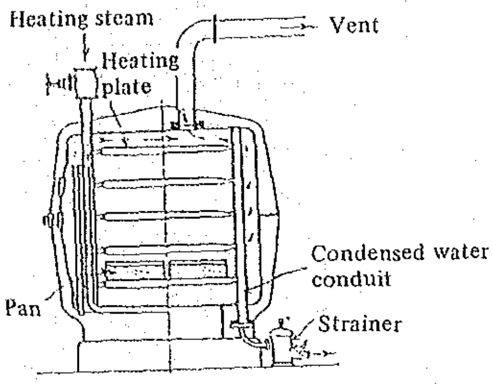
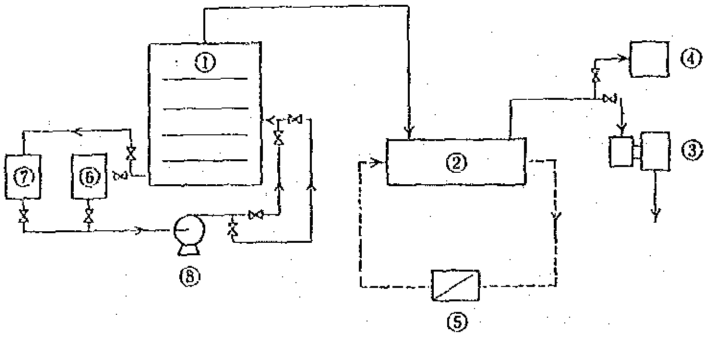


Fig. III–5–44 Box type vacuum dryer



① Drying chamber ② Condenser ③ High vacuum pump
④ Low vacuum pump ⑤ Refrigerator ⑥ Hot water tank
⑦ Chilled water tank ⑧ Pump

Fig. III–5–45 Distribution diagram of freeze vacuum dryer

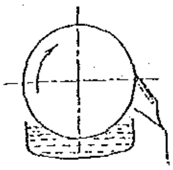


Fig. III–5–46 Drum dryer bottom feed

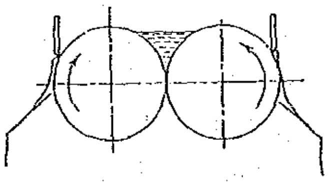


Fig. III–5–47 Drum dryer top feed

(2) Selection of Dryers

It is very important, not only in the production control of a chemical plant, but also in the economy of energy, to select an optimum dryer—taking into consideration properties of materials to be dried, specification of dry products, drying capacity, etc. The main points for selection of dryers will be described:

A) Properties of Materials to be Dried

Of the properties of the materials to be dried when wet, moisture content, particle size, adherability and allowable temperature are most important. In addition, it is necessary to seize combustibility, wearability, shrink characteristics, granulation, etc.

B) Properties of Dried Products

Consideration must be paid to what moisture content is required for the dried product, whether the dried product is powdered, granular or in other forms, and whether any special condition is given to the particle size, bulk specific gravity, color tone, flavor, etc.

C) Drying Capacity and Mode

This is one of the important factors for determination of the type of the equipment. Depending upon whether large quantities of materials are continuously dried or whether each of the small quantities are dried batch-wise, the type of equipment greatly differs even if the drying mode is the same. For example, when through-circulation drying is adopted, band through-circulation, rotary through-circulation and vertical through-circulation moving beds are recommended for continuous large quantities system. When in small quantities and batch-wise, box through-flow is suitable.

D) Heat Source

Study what can be used as a heat source and what kind of heat source should be used based on requisites for the dried product. Heat is generally given to the material to be dried by allowing hot air to come into contact with it. However, when the dried product is apt to be easily damaged by hot air, or when it is necessary to dry at low temperatures because the material is sensitive to heat, indirect heating with steam, etc., or indirect heating methods by means of an external heat source must be used. When no requisite for the dried product is provided, it is the simplest process to allow hot air to come into direct contact with the material. Therefore, the most economical heat source available or waste heat from other equipment etc. should be utilized. One example of the selection of dryers is shown in Table III-5-7.

(3) Rationalization in the Use of Thermal Energy

A) Pretreatment of Material

It is advisable to remove as much moisture as possible in the preceding process and to charge soluble material into the drying process after thickenning them as much as possible, or insoluble ones after dehydrating mechanically as much as possible. Although a dehydrater is comparatively expensive, the consumption energy is by far less compared with drying in which moisture is thermally removed by evaporation.

B) Prevention of Heat Loss

Since small-scale dryers have generally large specific surfaces and the heat loss is apt to be great, possibly exceeding 10% of heat input, they must be completely heat insulated. Next, there may be much more loss due to leakage of hot air than is expected and as such it is necessary to provide flanges or connections between moving and fixed parts inlet of material and outlet of products, etc. with seals according to the respective internal pressure.

C) Circulation of Exhaust

In hot air dryers, the amount of sensible heat carried out by exhaust is very great. To reduce this, it is important to reduce the amount of exhaust in addition to lowering the temperature. Circulating a portion of exhaust gas for re-use increases the thermal efficiency.

In the system of feeding large quantities of hot air at right angles to the material advance direction such as band through-circulation dryers, the exhaust is at high temperatures and has low humidity. Therefore, the efficiency can be increased by dividing hot air blowing into several sections and using exhaust on the latter side for the preceding side successively. When drying is performed at high temperatures, the drying rate hardly decreases because of the increase in humidity and as such circulation of the exhaust can be usually utilized.

D) Recovery of Sensible Heat from Exhaust

Recover sensible heat carried out by exhaust and utilize it to preheat drying air, in which case a plate type heat exchanger, heat pipe, etc. are suitable for the heat exchanger. However, the latter has a difficulty in that the equipment is expensive. When a heat exchange system is adopted, attention should be paid to the fact that dust, moisture, and others contained in the exhaust contaminate the heating surface and possibly may cause corrosion. Periodic cleaning and inspection are required.

Table III–5–7 Examples of selection of dryers

State when wet			Liquid, slurry		Freeze material	Paste sludge			Powdered			Granular			Lump like		Flaky		Single fiber		Continuous sheet		Material with a certain size			Paint
Examples of material			Milk, detergent, salt solution		Medicines	Filter cake, powdered coal, clay, titanium white, silica gel, starch			Clay, gypsum, PVC, pigment			Ilmenite, sand, soluble phosphatic fertilizer, active carbon			Ore, ground coal, coke		Leaf tobacco, flaked soybeans		Cellulose acetate, fibrous paste, rayon, linter		Paper, paper products		Wooden pillar, thick plate, hide, plywood, leaf tobacco, pottery			Paint, resin liquid
Method of treatment			Large quantities continuous	Small quantities continuous	Small quantities batch-wise	Large quantities continuous	Small quantities continuous	Small quantities batch-wise	Large quantities continuous	Small quantities continuous	Small quantities batch-wise	Large quantities continuous	Small quantities continuous	Small quantities batch-wise	Large quantities continuous	Small quantities batch-wise	Small quantities continuous	Small quantities batch-wise	Large quantities continuous	Small quantities batch-wise	Large quantities continuous	Small quantities continuous	Large quantities continuous	Large and small quantities batch-wise	Small quantities batch-wise	Continuous and batch-wise
Hot air drying	Hot air carrying	Flash				⊕			⊕			⊕														
		Spraying	⊕			○																				
	Material agitation	Rotation							⊕			⊕			⊕											
		Multiple-stage disc.							○			○														
		Groove type agitation							⊕			⊕														
		Multi-stage continuous fluidized bed							⊕			⊕														
		Horizontal multi-chamber fluidized bed							⊕			⊕														
		One stage continuous fluidized bed													⊕											
		Batch-wise fluidized bed									⊕			⊕												
	Material carrying and laying	Band type through-circulation				⊕						○			○		⊕		⊕				○			
		Rotary through-circulation							⊕			⊕			⊕		⊕									
		Vertical mobile bed type through-circulation										⊕			⊕											
		Box type batch-wise through-circulation						⊕			○			○		○		⊕		⊕					○	
		Tunnel				○			●			●			○		●						⊕			⊕
		Band							●			●					●									
		Box type						○			●			●		○		●						⊕		
		Drying sheets and the like																			⊕					
Indirect drying	Material agitation	Groove type agitation					⊕	⊕		⊕	⊕		⊕	⊕												
		Cylindrical agitation					⊕	⊕		⊕	⊕		⊕	⊕												
		Plate agitation						●																		
		Rotation with steam heating tube							⊕			⊕			⊕		⊕									
		Multi-stage agitation							○			○														
		Vacuum rotation									○			○												
	Material laying	Vacuum						○			○			○												
		Freeze			⊕																					
	Cylindrical type	Drum		⊕			⊕																			
		Cylinder																			⊕	⊕				

Remarks: Dryer's applicability is shown as follows: ⊕ > ○ > ●

Next, a method to directly recover heat retained in the exhaust without using heat exchangers should be studied. For example, when the exhaust is concentrated by allowing it to come into direct contact with the liquid to be dried in spray dryers, almost all sensible heat of the exhaust can be utilized close to the saturation.

E) Recovery of Latent Heat from Exhaust

The percentage of heat capacity used for evaporation of moisture to heat capacity consumed for the drying operation is very great. Since this evaporated vapor accompanies the exhaust, the thermal efficiency will remarkably increase if this latent heat is recovered. To recover, utilize it as a heating source for concentrating equipment or recover by means of a heat pump. Taking into consideration temperature and humidity of the exhaust, it is necessary to study for what purpose it can be utilized in the plant.

F) Recovery of Sensible Heat from Dried Products

When dried products are at comparatively high temperature, cool them by air and recover heat retained in them to utilize for preheating the drying air. Since the temperature of the dried products is not so high mostly, cool and at the same time, preheat air by means of a fluidized bed and the efficiency may be improved.

G) Others

It is often seen in chemical plants that air is used to cool reaction products, distillation towers and condensers for refrigerators. Although the temperature of the exhaust air in these cases is not so high, it can be mostly utilized as drying air because large quantities of air flow are available. In some cases, the temperature of the exhaust is so high that it can be fed as-is into dryers, resulting in high energy conservation.

4.2.5 Refrigerating Facilities

(1) Refrigerating Cycle

The mechanical refrigeration method utilized industrially has two systems; vapor compression, and absorption systems. Since the former is generally used, only the vapor compression system will be described here.

In a vapor compression system refrigerating plant, refrigerant gas which has reached high temperatures and high pressures compressed by a compressor release heat to the outside, become liquid in the condenser.

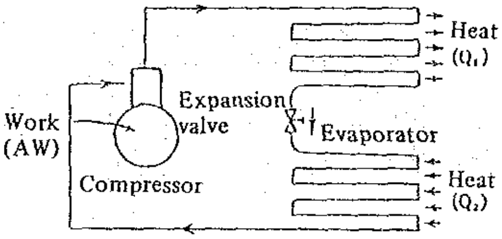


Fig. III–5–48 Refrigeration cycle

Next, being reduced in pressure while passing through the expansion valve, it enters the evaporator, and absorbing heat from the outside, it becomes gas again and then enters the compressor, which is called "Refrigerating Cycle". (See Fig. III-5-48) Midway through this refrigerating cycle, a work is made on the refrigerant from the outside within the compressor. Representing this work done as W kg·m, heat absorbed by the evaporator as Q_2kcal and heat released from the condenser as Q_1kcal, the following relations exist.

$Aw = Q_1 - Q_2$ $\quad$ $A = 1/427$ kcal/kg·m

To know various changes in the state of the refrigerant in the refrigerating cycle, diagrams generally used contain:

a. Pressure-Enthalpy diagram or Mollier diagram (P-i diagram):

Diagram with pressure P on ordinate axis and enthalpy i on abscissae axis.

b. Temperature-Entropy diagram (T-s diagram):

Diagram with absolute temperature T on ordinate axis and entropy s on abscissae axis.

P-i diagram is more convenient for various design calculations and operation analysis of a refrigerating plant and is mostly utilized.

Fig. III-5-49 shows the refrigerating cycle illustrated on the P-i diagram. Point A shows a state of refrigerant (low temperature and low pressure) sucked in the compressor and when compressed, it becomes a state of point B (high temperature and high pressure). At this time, it is theoretically an adiabatic compression and on an isoentropic curve. Compression work, W (kg·m/kg) is

$AW = i_b - i_a$

Where i_a: Enthalpy at compressor intake port (kcal/kg)

i_b: Enthalpy at compressor discharge port (kcal/kg)

A: 1/427 (kcal/kg·m)

Refrigeration effect in the evaporator (refrigerating capacity per kg of refrigerant) q_e is

$q_e = i_a - i_d$ (kcal/kg)

Where i_d: Enthalpy at evaporator inlet (kcal/kg)

Also, the ratio of refrigeration effect to compression work is called "Coefficient of Performance" and represented by E.

$E = (i_a - i_d)/(i_b - i_a)$

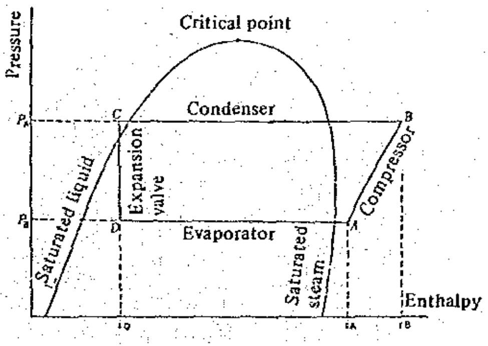


Fig. III–5–49

<Unit of Refrigerating Capacity>

Although it is convenient to determine units representing refrigerating capacity of a refrigerating facility beforehand, the value varies from country to country and, as such, care should be taken to prevent confusion.

For example,

(Japan)

Refrigerating capacity to turn 1 ton of water at 0° C into ice at 0° C for 24 hours is called "1 Refrigerating ton" and equivalent to 3,320 kcal/h.

(U.S.A.)

200 BTU/min. is called "1 Refrigerating Ton" and equivalent to a heat capacity used to melt 2000 pounds of ice at a temperature of 32° F for 24 hours. (200 BTU/min. 3,023 kcal/h)

P-i diagrams for each refrigerant are shown in Fig. III-5-50 and Fig. III-5-58.

(2) Compressors for Refrigerant Gas

Compressors for refrigerating facilities are classified into reciprocating, centrifugal and rotary types by compression mechanism. Reciprocating type covers small capacity to large capacity and can be used at almost any temperature. However, the centrifugal type is cheaper in equipment cost for larger capacity, but comparatively expensive for the larger compression ratio. Also, the efficiency will be worse for small capacity (less than 40 m^3/min).

Screw compressors, a kind of the rotary type, have little dependance in efficiency on the capacity, and new compressors at one stage equivalent to the reciprocating type at two or three stages in compression ratio have been developed and have been recently widely used for refrigerating facilities. Refrigerants generally used for each compression type are shown in Table III-5-8.

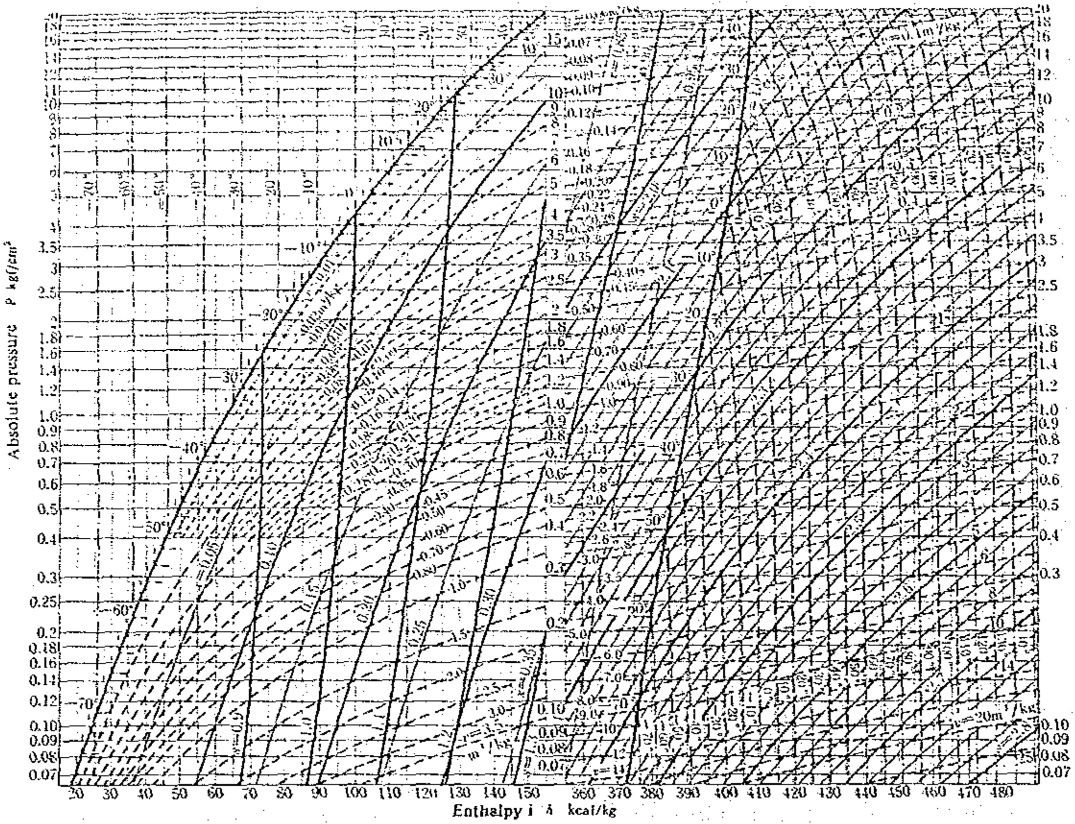


Fig. III–5–50 P–i Diagram of ammonia

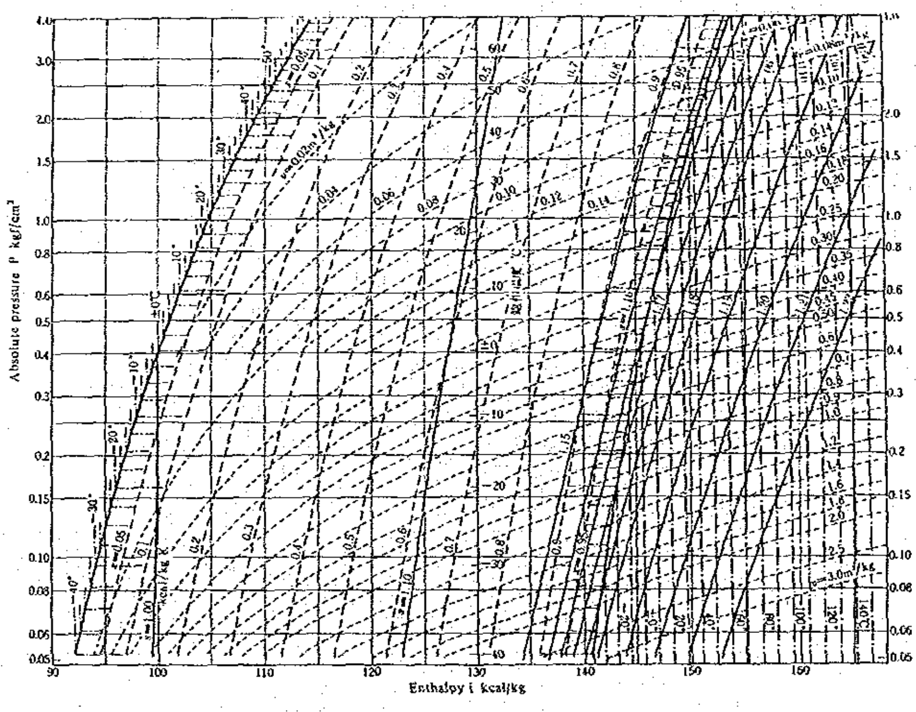


Fig. III–5–51 P–i Diagram of R-11

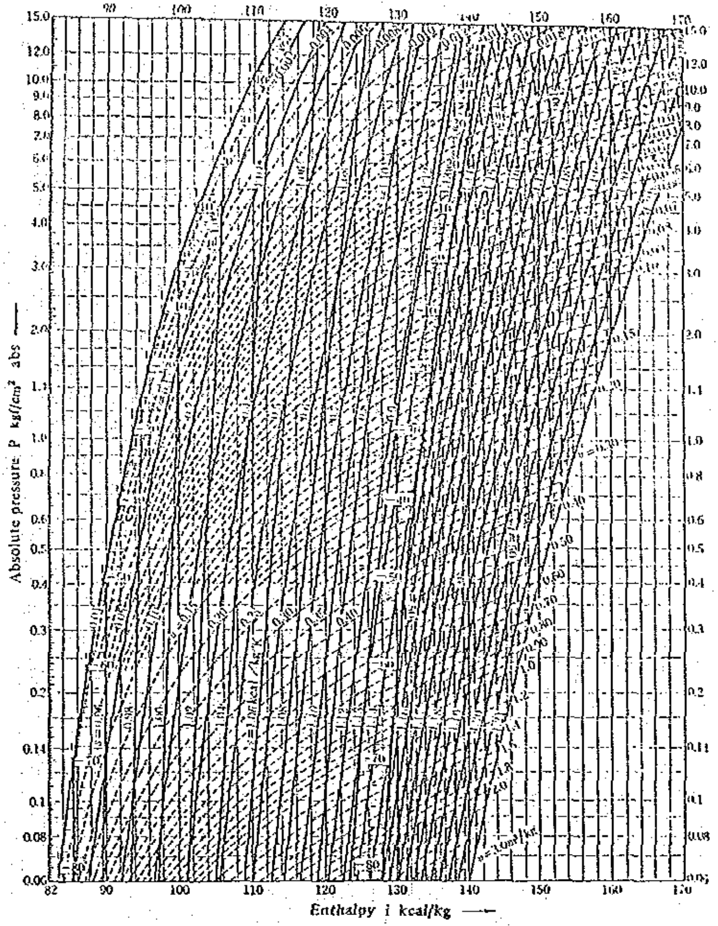


Fig. III–5–52 P-i Diagram of R-12

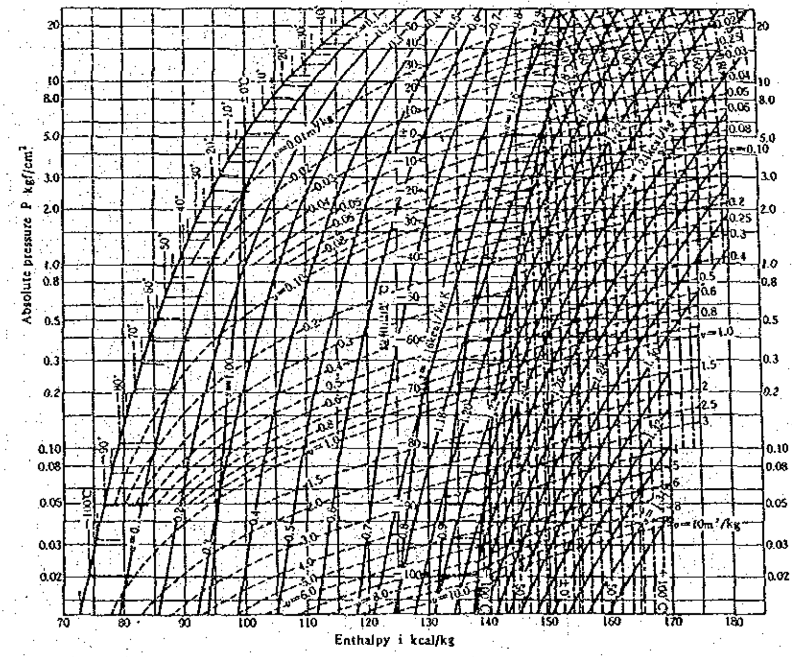


Fig. III–5–53 P–i Diagram of R-22

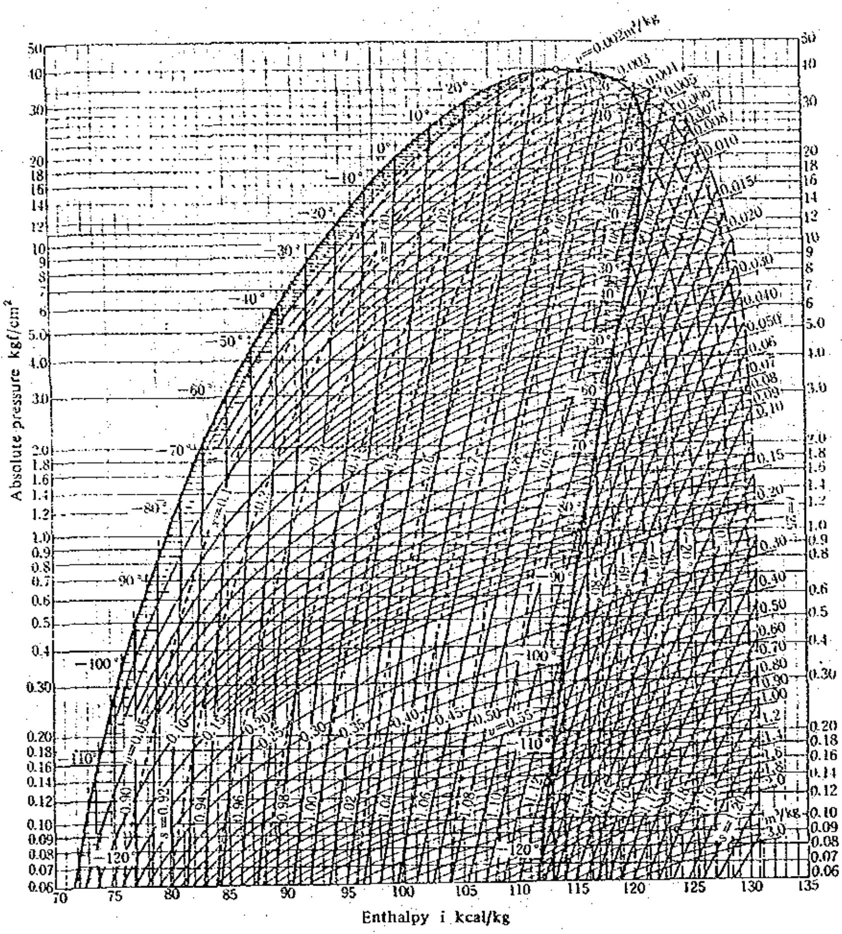


Fig. III–5–54 P–i Diagram of R-13

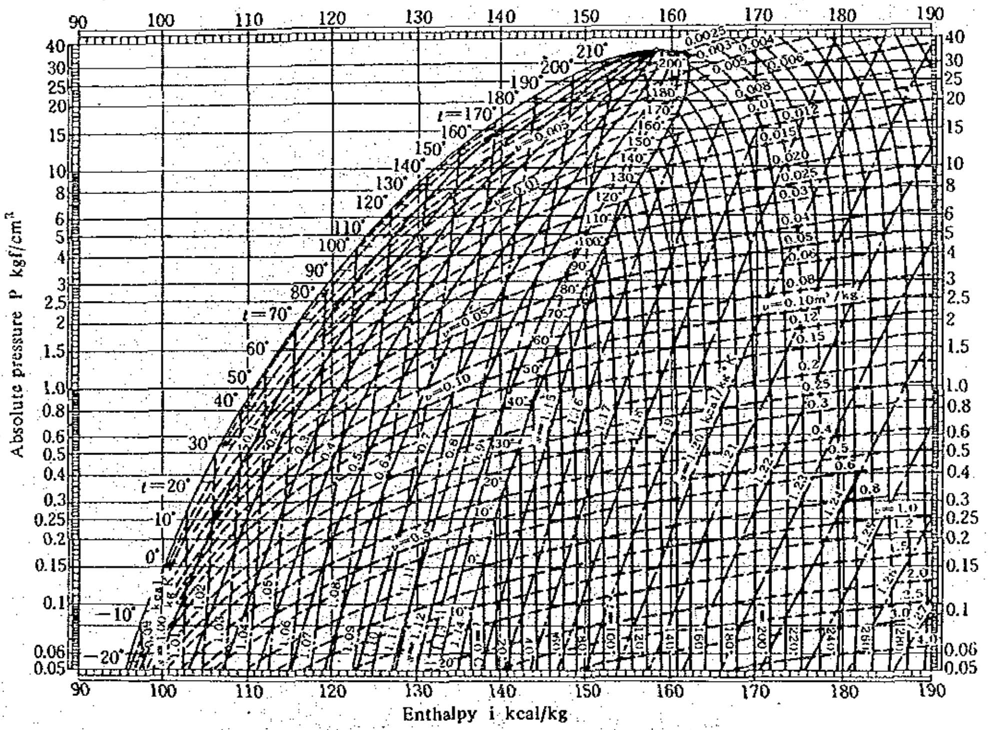


Fig. III–5–55 P–i Diagram of R-113

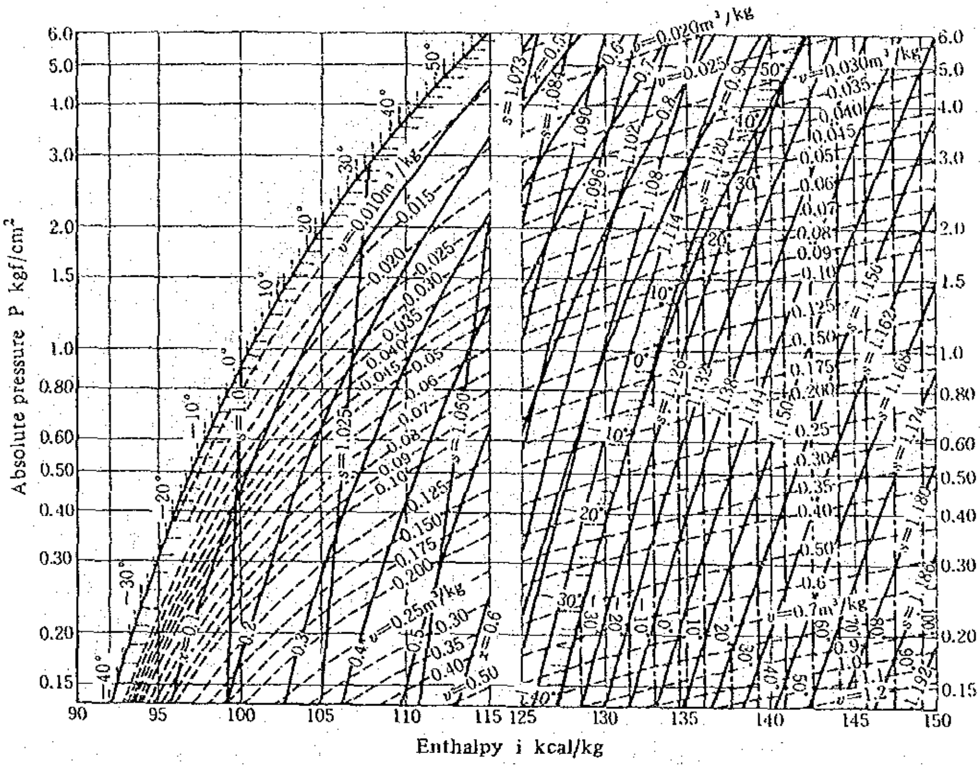


Fig. III–5–56 P–i Diagram of R-114

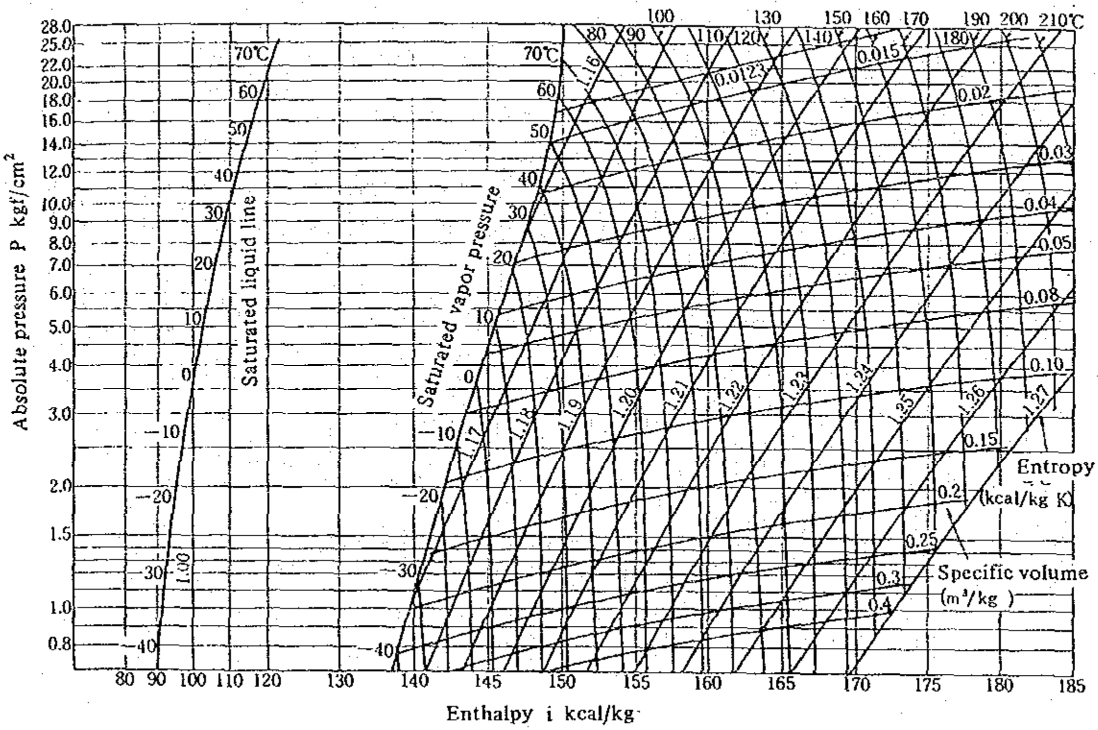


Fig. III–5–57 P–i Diagram of R-500

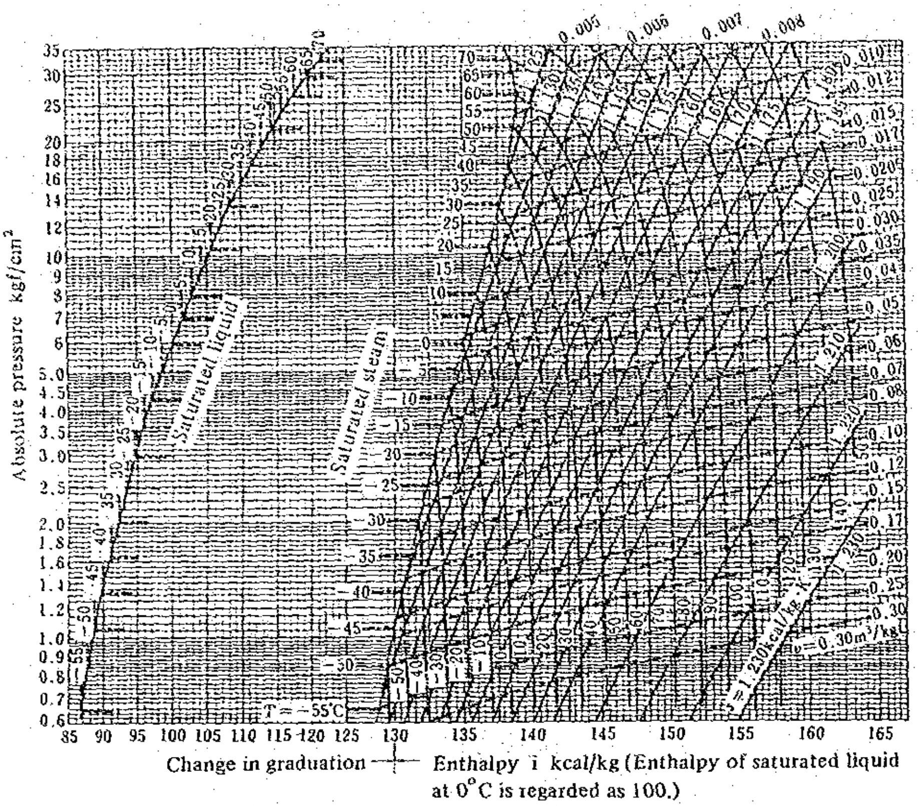


Fig. III–5–58 P–i Diagram of R-502

Table III–5–8 Compressor and refrigerant

Type of compressors	Refrigerant to be used
Reciprocating type	High and medium temperature areas —— R–12, R–22, NH_3 Low temperature area —— R–13, R–14, Ethane, Ethylene
Centrifugal type	Small capacity high temperature area —— R–113, R–114 Large capacity high temperature area —— R–11 Low temperature area —— R–12, NH_3
Rotary type	R–12, R–22, NH_3

Also, the class of refrigerants and the system of refrigerating cycles at various evaporation temperatures when a reciprocating compressor is used are shown in Table III-5-9. When the compressor is operated at a high compression ratio, lowered volumetric efficiency, deterioration of lubricating oil due to rising of discharge gas temperature, carbonization and damage to discharge valve, etc. tend to occur. One stage compression is usually performed at a compression ratio of 8 to 10 or less and a two or three stage compression system is adopted for a higher compression ratio.

When the evaporation temperature is −80°C or below, refrigerants for high temperature use such as R-22, ammonia, etc. have very low vapor pressure corresponding to the evaporation temperature and become a high vacuum, lowering volumetric efficiency of the compressor remarkably.

Accordingly, the binary refrigerating cycle is mostly used in this temperature range (See Table III-5-9). In this binary refrigerating cycle, a refrigerant with comparatively high vapor pressure is used as a low temperature level refrigerant.

Table III−5−9 Refrigeration cycle of reciprocating refrigerators

Evaporation temperature range	Refrigerant	Refrigeration cycle
+5 ~ −35°C	R−12, 22, NH_3	1-stage or 2-stage compression
−35 ~ −60°C	R−22	2-stage compression
−60 ~ −85°C	R−22	3-stage compression
	R−22 & R−13	2 cycle Low temperature R−13 1-stage compression High temperature R−22 2-stage compression
−85 ~ −100°C	R−22 & R−13	2 cycle Low temperature R−13 2-stage compression High temperature R−22 2-stage compression
	R−22 & Ethane	2 cycle Low temperature Ethane 2-stage compression High temperature R−22 2-stage compression
−100 ~ −130°C	R−22 & Ethylene	2 cycle Low temperature Ethylene 1-stage or 2-stage compression High temperature R−22 2-stage compression
	R−22 & R−14	2-cycle Low temperature R−14 1-stage or 2-stage compression High temperature R−22 2-stage compression

(3) Refrigerants

Refrigerants are mediums having thermodynamic changes in refrigerating cycle, and substances with the following special properties:

A) Physical Properties

a. The critical temperature is higher than atmospheric temperatures and the freezing point is low.

b. Heat of evaporation is great (small refrigerant circulating amount suffices).

c. Ratio of specific heat of gas, namely, ratio (specific heat at constant pressure)/(specific heat at constant volume) is small.

d. Coefficient of performance is great.

e. Specific volume of gas is small (small volume of compressor suffices).

f. Condensing and evaporating pressure are adequate.

B) Chemical Properties

a. Chemically stable under service conditions.

b. Inert and not corrosive.

c. Solubility in lubricating oil is small.

d. Low viscosity in both gas and liquid.

e. High heat conductivity.

Characteristic values for each refrigerant are shown in Table III-5-10 and Table III-5-11.

(4) Brine

The solution of salts used as a cooling medium in indirect refrigerating methods is called "Brine". Salts mostly used as brine are calcium chloride ($CaCl_2$) and in addition there are sodium chloride ($NaCl$), magnesium chloride ($MgCl_2$), methanol, ethanol, ethylene glycol, glycerine, etc. Fig. III-5-59 and Fig. III-5-60 show the specific heat of brine, and the specific weight and freezing temperature respectively.

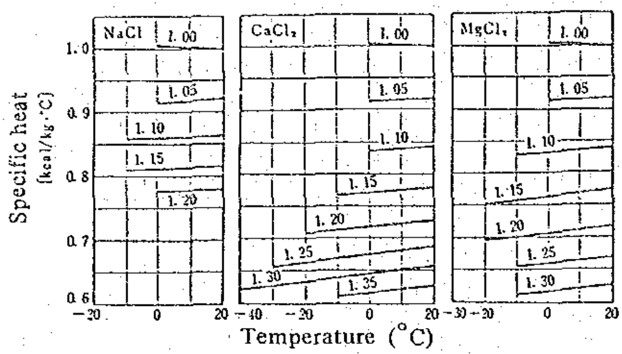


Fig. III–5–59 Specific heat of brine

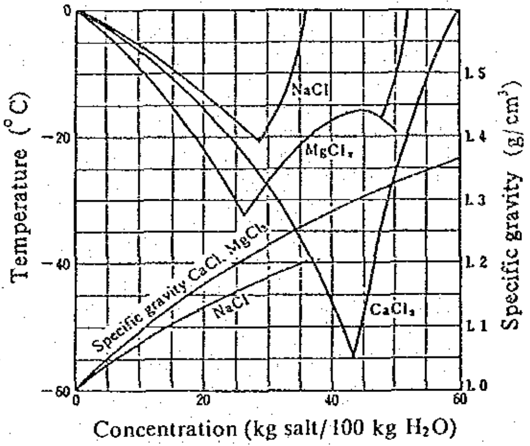


Fig. III–5–60 Freezing temperature and specific gravity of brine

(5) Rationalization in the Use of Refrigerating Energy

A) Purge of non-condensable gas

There may be non-condensable gas contained in a circulating refrigerant. The kinds of this gas are N_2, O_2, H_2, Cl_2 and carbon hydride, etc. Containment of this gas is caused by insufficient removal of air in the equipment before pouring the refrigerant into the equipment, decomposition of the lubricating oil and chemical reaction in the equipment, etc. Non-condensable gas contained in the refrigerant may impede heat transfer in the condenser, or occupy a portion of space in the equipment, thus reducing the heat transfer surface. As a result, the condensing pressure increases, increasing the refrigerator load and lowering the refrigerating capacity. To check whether non-

Table III−5−10 Refrigerant properties (for High temperature)

Classification of refrigerants		Ammonia	Methyl chloride	Fleon R-11	Fleon R−12	Fleon R−22	Propane	Propylene	n-butane	i-butane
Chemical formula		NH_3	CH_3Cl	CCl_3F	CCl_2F_2	$CHClF_2$	C_3H_8	C_3H_6	C_4H_{10}	C_4H_{10}
Molecular weight		17.03	50.48	137.38	120.9	86.48	44.06	42.08	58.12	58.12
Boiling point (at atmospheric pressure)	°C	−33.3	−23.8	23.6	−29.5	−40.8	−42.3	−41.0	−0.5	−11.7
Freezing point (at atmospheric pressure)	°C	−77.7	−97.78	−111.1	−158.2	−160	−189.9	−185.2	−135	−145
Critical temperature	°C	133	143	198	111.5	96	94.4	91.8	152.2	134.9
Critical pressure	kg/cm² (abs)	116.50	68.11	44.65	40.92	50.34	46.51	47.0	38.7	37.2
Evaporation pressure at −15°C	〃	2.410	1.487	0.210	1.863	3.025	2.946	3.70	0.576	0.921
Condensation pressure at 30°C	〃	11.895	6.658	1.30	7.592	12.269	10.918	13.10	2.92	4.18
Compression ratio at Te=−15°C and To=30°C		4.94	4.48	0.19	4.075	4.056	3.706	3.54	5.07	4.54
Heat of evaporation at −15°C	kcal/kg	313.53	100.43	45.82	38.59	51.998	94.56	96.10	95.00	88.6
Refrigerating capacity at standard refrigerating cycle	kcal/kg	269.03	85.43	38.57	29.57	40.16	70.68	72.8	74.2	65.3
Refrigerant circulation amount per ton of Japan refrigerating capacity	kg/hr	12.34	38.86	86.08	112.27	82.67	46.97	45.6	44.7	50.8
Specific volume of saturated steam at −15°C	m³/kg	0.5087	0.2791	0.7659	0.0927	0.0778	0.1548	0.142	0.623	0.400
Specific volume of saturated liquid at 25°C	ℓ/kg	1.6588	1.098	0.6788	0.764	0.8384	2.0253	0.647	1.740	1.81
Compressor discharge temperature	°C	98	77.78	44.44	37.78	55.00	36.11	42.0	32.0	27.0
Theoretical piston displacement per ton of Japan refrigerating capacity	m³/hr	6.278	10.842	65.934	10.408	6.420	7.272	6.48	27.8	20.3
Theoretical indicated horsepower per ton of Japan refrigerating capacity		1.08	1.047	0.990	1.055	1.064	1.079	1.09	1.02	1.14
Coefficient of performance		4.87	5.32	5.23	4.90	4.87	4.80	4.78	5.10	4.53

Table III−5−11 Refrigerant properties (for Low temperature)

Classification of refrigerants		Fleon R−13	Ethane	Ethylene	Methane
Chemical formula		$CClF_3$	C_2H_6	C_2H_4	CH_4
Molecular weight		104.40	30.07	28.05	16.04
Boiling point (at atmospheric pressure)	°C	−81.4	−88.6	103.90	−161.49
Freezing point (at atmospheric pressure)	°C	−182.2	−172	−169.5	−182.48
Critical temperature	°C	28.8	32.3	9.2	−82
Critical pressure	kg/cm² (abs)	39.47	49.8	51.7	45.80
Evaporation pressure at −100°C	〃	0.3392	0.536	1.28	26.60
Condensation pressure at −30°C	〃	8.59	10.86	19.7	Critical point or above
Compression ratio at Te=−100°C and To=30°C		25.3	20.3	15.4	−
Heat of evaporation at −100°C	kcal/kg	37.85	121.7	113.4	72.8
Refrigerating capacity at standard refrigerating cycle T_E=−100°C and To=−30°C	〃	21.84	77.0	69.3	−
Refrigerant circulation amount per ton of Japan refrigerating capacity	kg/hr	152	43.1	47.9	−
Specific volume of saturated steam at −100°C	m³/kg	0.407	0.880	0.378	0.022
Specific volume of saturated liquid at −30°C	ℓ/kg	0.769	2.17	2.27	−
Compressor discharge temperature	°C	18	36	49	−
Theoretical piston displacement per ton of Japan refrigerating capacity	m³/hr	61.9	37.9	18.1	−
Theoretical indicated horsepower per ton of Japan refrigerating capacity		3.29	4.1	3.3	−
Coefficient of performance		1.57	1.7	1.6	−

condensable gas is contained, stop operation of the equipment and pass water through only the condenser. If the pressure, when the water temperature becomes equal to the refrigerant temperature after a long wait, is higher than the vapor pressure of refrigerant, non-condensable gas is contained.

For example, if there is a difference in pressure equivalent to 10° F, it is said that condensing temperature rises 20 to 25° F during actual operation.

For purging non-condensable gas, a special purging device is provided at a place where gas has a tendency to accumulate on the top and end of the condenser.

B) Contaminated Heating Surface

When well water with high hardness or dirty water is used for the water-cooled condenser, scale sticks to the heating surface, impeding the heat transfer. As a result, the condensing temperature and pressure increase (See Fig. III-5-61), thus increasing consumption power of the compressor (See Fig. III-5-62).

Since the condensing pressure largely depends upon the temperature of cooling water, check the relation between the water temperature and the condensing pressure when the heating surface is clean (which is called "Normal Value"), always compare the condensing pressure with the normal value during operation and clean the heating surface when the difference between both pressures becomes large.

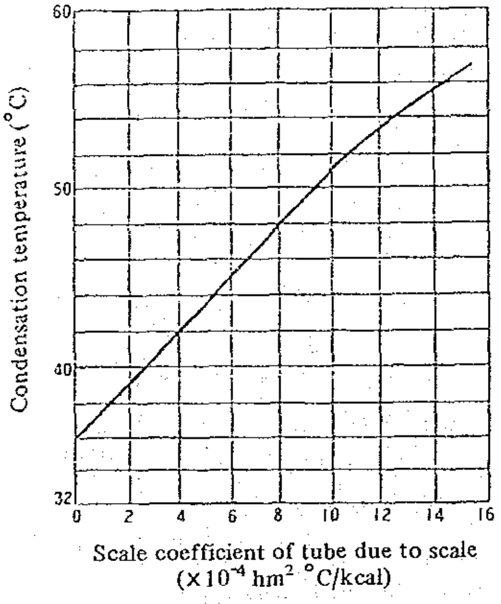


Fig. III-5-61

(3) Effect of scale on refrigerating capacity (Fig.-3)

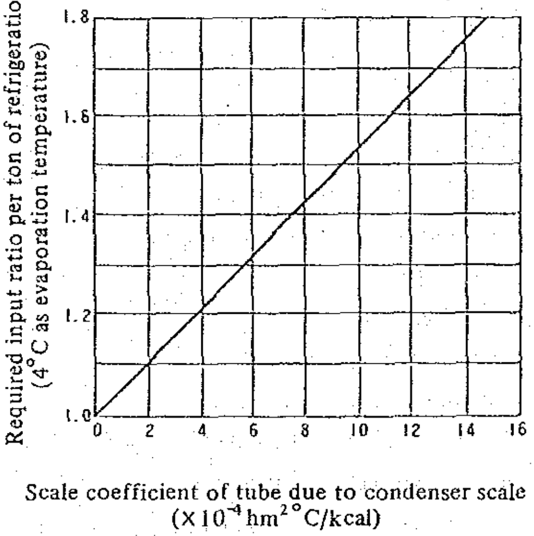


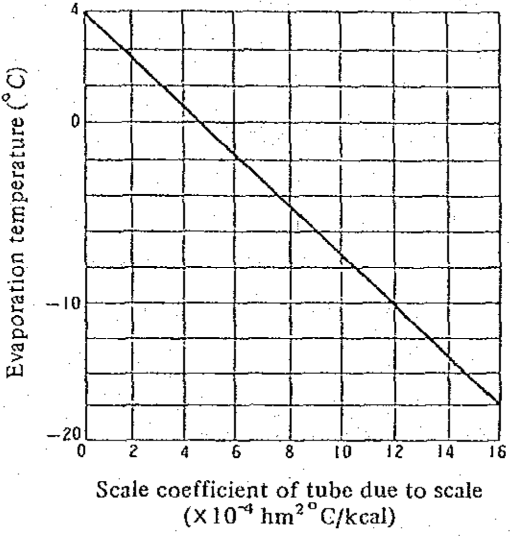
Fig. III-5-62

For air-cooled condensers, do not locate them near any heat-generating equipment and indoors, but utilize fresh air outdoors, since the temperature of air for cooling affects the power of consumption.

Also for evaporators, a contaminated heating surface lowers the evaporation temperature and pressure (See Fig. III-5-63) to provide necessary coldness, leading to increase in consumption power. Therefore, care should be taken during operation.

C) Capacity Control Measure Equipment

When refrigeration load decreases, the evaporation temperature falls and evaporation pressure also falls together with it. Therefore, the amount of intake of the compressor must be reduced. In the reciprocating type compressor, there are the following systems:



(2) Effect of scale on evaporation temperature

(Fig.-2)

Fig. III-5-63

a. "Suction valve releasing system" for Multi-cylinder type in which the intake valve is released according to load and the cylinder is rendered free of load step-wise.

b. "Cylinder head by-pass system" in which a by-pass valve is provided in each cylinder to stop compression.

c. "Hot gas by-pass system" in which discharge gas at a high temperature is introduced between expansion valve and evaporator.

d. "Clearance increase system" in which the cylinder is provided with a clearance pocket to reduce apparent volumetric efficiency.

e. "Motor speed control system" to change speed of a driving motor.

Use of any of systems a, b and c reduces the consumption power.

Since system c is constant in consumption power, it is desirable to limit its use to reduction in capacity of 0 to 25%

In the centrifugal type compressor, it is simplest to close the discharge valve. However, the operation is hindered when in the surging area. In "Suction vane control system", several guide vanes are provided at the intake port to change the capacity by changing the angle of these vanes. This system is recommendable because it causes no surging, but saves the consumption power.

D) Cold Insulation

When the low temperature portion of the equipment and piping is exposed even a little, invasion of heat increases the refrigeration load. Moreover, when the temperature of the air in contact with the surface reaches the dew point, dew condensation occurs, the heat insulation material absorbs this water, thus greatly increasing the heat conductivity and lowering the insulation efficiency remarkably.

Deterioration of insulation due to moisture condensation can be prevented by sticking the heat insulation material to the surface with adhesive and by completely covering the external surface of the insulation material with asphalt roofing (2 to 3 layers) so that outside air may not enter the insulation material.

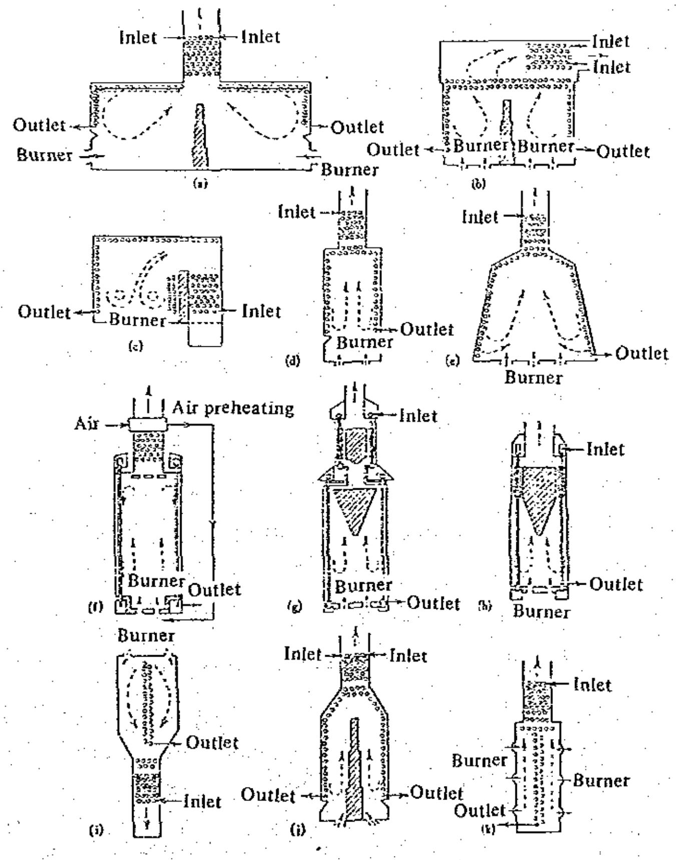
4.2.6 Indirect Heater by Direct Flame Heating

In some of the chemical plants, process fluids are heated by combustion equipment in place of steam, which is represented by pipe still and thermal-liquid heater. These will be described as follows:

(1) Pipe Stills

Pipe stills are mostly used for heating petroleum in petroleum refining and petrochemical plants. Pipe stills consist of radiation and convection portions; the former directly absorbs radiation from flame and the latter absorbs heat from combustion gas through convection.

Fig. III-5-64 shows the arrangement of the heating tube and flow direction of combustion gas in typical types of pipe still. Merits and demerits of the respective types are described:



(a) Large box-type (b) Seperate-convection (Lumnus)
(c) Down-convection (d) Straight-up (Boro) (e) A-frame(Kellogg)
(f) Circular (DeFelorez) (g) Large isoflow (Petrochem)
(h) Small isoflow (Petrochem) (i) Equiflux (UOP)
(j) Double-upfired (UOP) (k) Radiant-upfired (Selas)

Fig. III–5–64 Various furnace types of pipe still

a) Impingement of flame

Excessively large flame tends to damage the tubes. Especially, convection portion inlet in type (c) and lower portion in types (j) and (d) are susceptible to damage.

b) Heat distribution

Types (a) and (c) tend to be uneven in heat distribution because they have large space within the furnace. Other types have few problems.

c) Two-system heating

Since types other than type (c) are of similar configurations, even heating is almost possible by arranging two systems similarly. When two systems are different in heating capacity, use a type with partitions.

d) Control of heating capacity

Types (i) and (k) are capable of controlling heating capacity optionally and are suitable particularly for heating at high temperatures of 540 to 810°C. Cylindrical types in (f), (g) and (h) and types with spacious radiation heat receiving surfaces can be operated at low load.

e) Capacity

Types (c), (d), (h), (i) and (k) are suitable for small capacity and types (a), (b), (c) and (j) for large capacity.

f) Stack

Types (a), (b), (c) and (i) need a stack, but other types need no stack because the furnace itself serves as a stack.

g) Others

Since types (g) and (h) use finned tubes in the convection portion, heat transfer capacity in the convection portion may be more than that in the radiation portion. Circulation of combustion gas lowers temperature of the flame, but increases convection heat transfer.

The furnace of a similar figure is uniform in heat load, causing no coking, discoloration, decomposition, etc., and has many merits. Radiation heat transfer capacity is generally 16,000 to 54,000 kcal/m^{2}h. However, accumulation of coke remarkably lowers the heat transfer coefficient and therefore periodical cleaning is required. Thermal efficiency of the pipe can still reach 80 to 90% by reducing the exhaust gas loss and recovering heat retained in fluid.

Examples of energy saving countermeasures for pipe stills carried out in Japan are shown:

- Increase in efficiency by turning tubes in convection portion into stud tubes.
- Preheating of air by installation of heat exchanger for exhaust gas/combustion air (about 290°C, Fig. III-5-65)
- Stable combustion at low air ratio (1.2 or less) by the adoption of a low excess air burner.

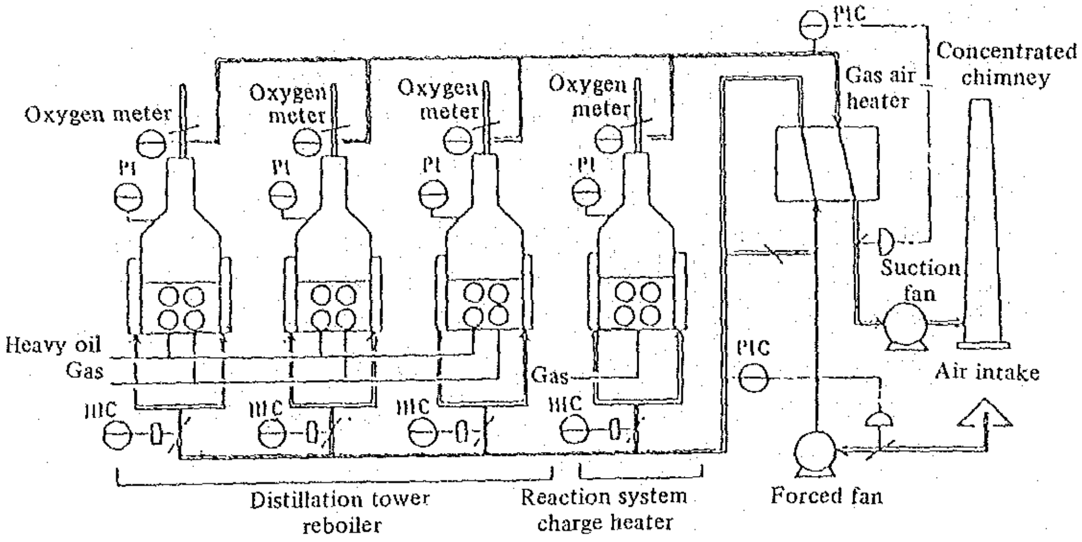


Fig. III–5–65

(2) Thermal-liquid Heater

Operation at 250 to 350° C is frequently required in vacuum distillation such as plasticizer, fatty acid, higher alcohol, organic chemicals, etc., vacuum deodorizing for vegetable and hardened oils, and reaction such as esterification, condensation reaction, hydrogenation and dehydrogenation reaction, etc. Since, for example, a heating source at 300° C can be obtained under a pressure of 1 atmospheric pressure by the use of thermal-liquids, this is a convenient method as compared with electric heating, direct flame and hot water heating methods. Although this has special features such as uniform heating, precise temperature control, quick heating and cooling, etc., in addition to low pressure, it is expensive in equipment and thermal-liquids.

Thermal-liquids generally used are shown in Table III-5-12. At 250 to 350° C organic heat transfer oil is used, at 350 to 500° C molten salts such as KNO_3, $NaNO_2$, etc., and at 450 to 700° C molten metal such as Na, K, Hg, etc.

For heating the thermal-liquid, boiler types similar to small boilers or a water-tube type are used. (See Table III-5-13) Heating by means of thermal-liquid is classified by the circulation system, as follows:

A) Jacketed direct flame type (see Fig. III-5-66)
B) Vapor heating systems using evaporators
a. Gravity circulation type (See Fig. III-5-67)
b. Forced circulation type (See Fig. III-5-68)
c. Gravity/Forced combination circulation type
C) Liquid heating systems
a. Heat siphon type (See Fig. III-5-69)
b. Forced circulation type (See Fig. III-5-70)

Table III–5–12 Physical properties of thermal fluids

Property	Dowtherm A*	Dowtherm E*	Fused salt Hi Tec	Oil Mobiltherm 600	Oil Mobiltherm light	Hydrotherm 750-200	Hydrotherm 700-160	Therminol FR-2	Mercury	NaK
Chemical formula	$(C_6H_5)_2O$ $(C_6H_5)_2$	$C_6H_4Cl_2$	$NaNO_2$ $NaNO_3$ KNO_3						Hg	44 wt. NaK
Molecular weight	165	147	92						200	
Specific gravity at 212°F	0.997	1.181	1.98(300°F)	0.90	0.930	1.11	1.08	1.38	13.35	0.84(600°F)
Melting point, °F.	53.6	−6.7	288	20 (pour point)	−20(pour point)	5 (pour point)	−40(pour point)	20 (pour point)	−38.7	65
Boiling point, °F. (atm. pressure)	495.8	352		>600	>400			644	674.4	1,518
Flash point, COC. °F	255	155		360	250	475		375		
Specific heat of liquid. B.t.u./(lb.)(°F.)	(0.326(496°F.)	0.412(352°F.)	0.373(300°F.)	0.580(500°F.)	0.58(300°F.)	0.56(600°F.)	0.64(500°F.)	0.333(500°F.)	0.033(212°F.)	0.25(600°F.)
Heat of vaporization, B.t.u./lb.	125.0	119.0							117.0	
Heat of fushion. B.t.u./lb	64	38	35						5.1	
Cubical expanshion coefficient	0.00043		0.00020	0.00035	0.00035			0.00039	0.000101	
Absolute viscosity of liquid. centipoise	0.30(600°F.)	0.30(400°F.)	1.7(800°F.)	0.595(500°F.)	0.873(300°F.)	0.572(600°F.)	0.605(500°F.)	0.63(500°F.)	1.23(200°F)	0.24(600°F.)
Surface tension (contact with air), dynes/cm	43	37				37			487	105
Thermal conductivity liquid, B.t.u./(hr.)(sq.ft.)(°F./ft.)	0.076	0.064	0.35	0.067	0.0652	0.0590	0.072	0.057	4.85	15.6

* The Dow Chemical Company.
E. I. du Pont de Nemours & Co., Explosives Department, Wilmington, Del.
Mobil Oil Corp.
American Hydrotherm Corp.
Monsanto Co.

Table III–5–13 Thermal fluids heaters

Type	Vertical type	Horizontal multi-tube type	Marine type	Water tube type
Heat capacity (kcal/hr)	50,000~200,000	50,000~15,000	100,000~600,000	600,000 or more
Thermal efficiency (%)	50~55	50~55	about 70	70~75
Radiant section thermal load (kcal/m²·hr)	15,000	–	15,000	–
Convection section thermal load (kcal/m²·hr)	8,000	8,000	1,000	15,000~20,000
Construction	Simple · Small	Simple · Large	Simple · Medium	Dual drum water tube type
Thermal fluid	Small quantities	Large quantities	Large quantities	1 m³/10,000 kcal
Natural circulation system	Unsuitable	Suitable	Suitable	Unsuitable
Burner	Short flame burner	Fore-fire burner	Short flame burner	Easily adjustable burner
Applications	for small capacity	for small capacity	for general purposes	for large capacity

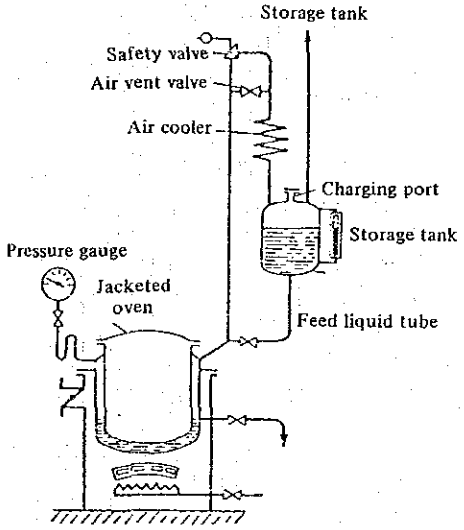


Fig. III–5–66 Jacket system heating method

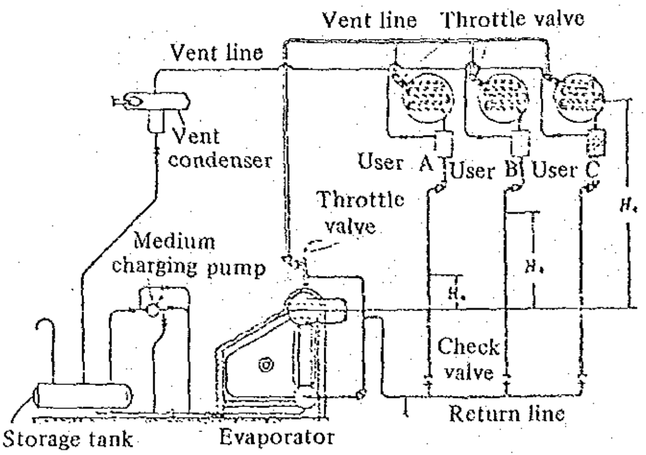


Fig. III–5–67 Multi-user gravity circulation system

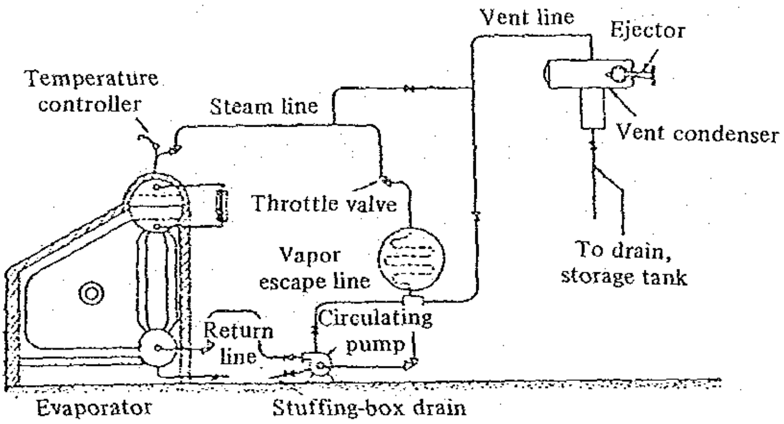


Fig. III–5–68 Forced circulation system

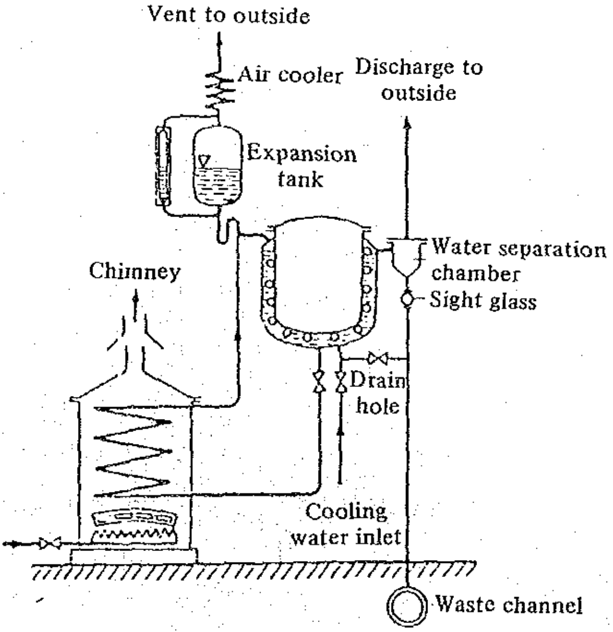


Fig. III–5–69 Thermosyphon system heating method

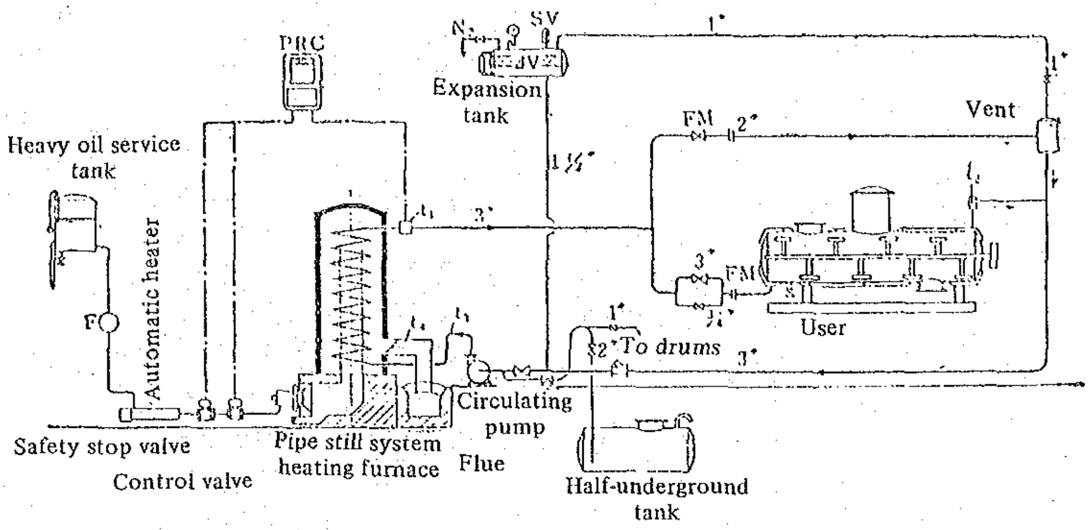


Fig. III–5–70 **Distribution diagram of pump circulating heater**

It is needless to say that Basic Data in item 4.1 applies to these equipment, and special precautions for use of thermal liquids are described below:

Since the remaining air in jackets, heating tube and user's coil, etc. remarkably lowers heat transfer coefficient and, at the same time, acclerates deterioration due to oxidization of thermal liquids, it is necessary to remove the air in the system completely.

In a method by the use of an evaporator, an adverse effect on the heat transfer coefficient is particularly significant. Since air bleeding is difficult when the user is coil, it is desirable to purge as much air as possible in the following way: a box for vent is provided at the end of the coil to provide the box with a vent and, besides, the evaporator is provided with a vent also and, moreover, the system is made a vacuum before charging the thermal-liquid.

In a temperature control method in type by the use of an evaporator, the simplest method is to only maintain vapor temperature (pressure) at a specified value by controlling the evaporator burner and to provide with no valve for control.

Maintenance is simple, because valves, pumps and control valves which are very likely to leak are not provided. This method is good enough for batch type deodorizer, etc.

Besides, there is a method to perform precise temperature control by means of vapor feed valve in conjunction with the burner control method. This is based on a certain relationship steam pressure due to throttliing of the valve and lowered heating thermal-liquid, and it is widely utilized.

(See Fig. III-5-71 and Fig. III-5-72)

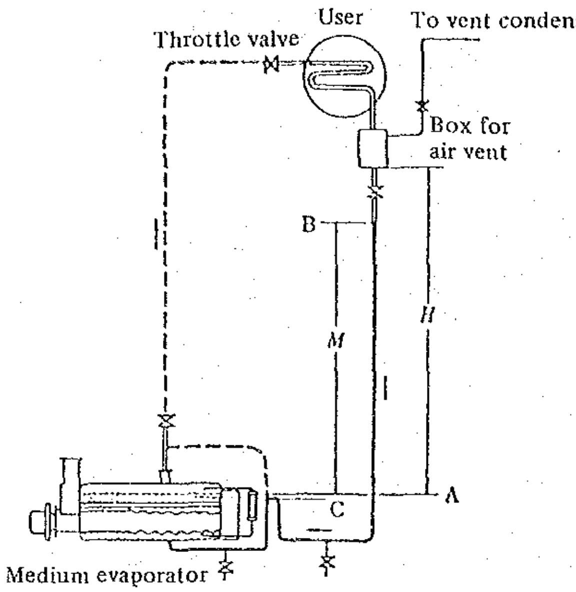


Fig. III–5–71
Evaporator using single user heating method

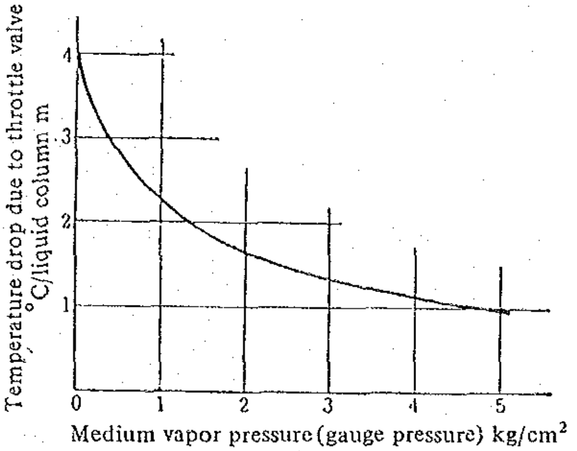


Fig. III–5–72
Temperature drop ratio due to throttle valve

III. Guideline for Rationalization of Energy Use

6. Food

Contents

1. Character of Guide Line

This Guide Line is a summary of technical matters considered important for the promotion of energy saving at the factories of the food industries. The Guide Line is to be used for the following purposes.

1) (1) As technical reference for factory's engineers when they plan to rationalize use of energy in the factory.

   (2) As a diagnostic guidance manual.

   (3) As referential data for determining the progress of rationalization.

   (4) As a text for seminars.

2) Descriptive level which should be understandable by engineers having only 4 to 5 years' experience of actual service after college graduation, but not actually working in the subject industries.

3) In consideration of the present industrial status of the Kingdom of Thailand, the descriptive coverage is limited to the process-related matters of the factories which we diagnosed. Also, the basic items and numerical values regarding this process —energy-saving techniques and referential instances or actual records — are described.

It is hoped that the Guide Line prepared here will be further supplemented and substantiated by the addition of information obtained in future through NEA's own factory diagnosis and other means.

For information, the Guide Line contains standard values published by the Japanese Government (Ministry of International Trade and Industry) as a basis for judgement in promoting energy saving for factory managers through its notification.

(1) The standard values are the most frequent values (refer to Fig. III-6-1) of statistical distributions of numerous examples. As such they represent a realistic level for factory managers to attain without difficulty from the technical and economic points of view.

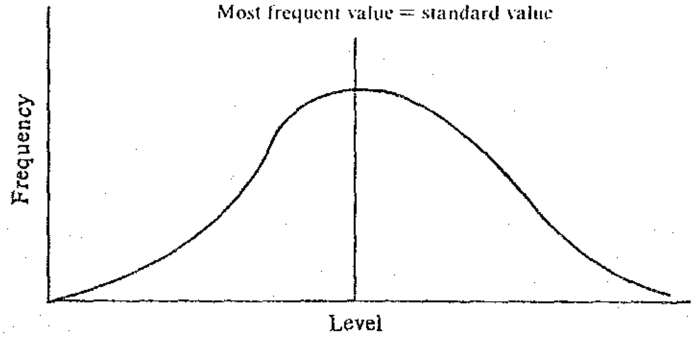


Fig. III-6-1

(2) The standard values do not necessarily represent the values which factory managers should be satisfied with after reaching them and also the minimum values which it must reach by all means. These values are rather those designed to improve the inferior value toward an average level, thus shifting the whole distribution of values into a better direction. Therefore, the most frequent value will be resought and a new standard value established after the elapse of a certain period.

The standard value establishment plan described in the report was prepared based on these standard values considering the present industrial status of the Kingdom of Thailand.

These standard values will be a starting point for the establishment of standard values for the rationalization of energy use in industry of the Kingdom of Thailand. It is recommended that the Kingdom of Thailand itself accumulates data during factory diagnosis to be put into practice, and evaluates it periodically and revises or newly establishes standard values.

2. Characteristics of Energy Consumption

2.1 Production process and main equipment

2.1.1 Canning industries (tuna, bonito and sardine)

The production process is shown in Fig. III-6-2. The canning industries of marine products in Thailand, recently, are rapidly growing and moving into the limelight as an export industry with an international competitiveness. The industries consume much heat energy for cooking and sterilization, the power consumption is also increasing with the extention of refrigerating and storage facilities, and with the completion of a waste water treatment facility as a pollution measure.

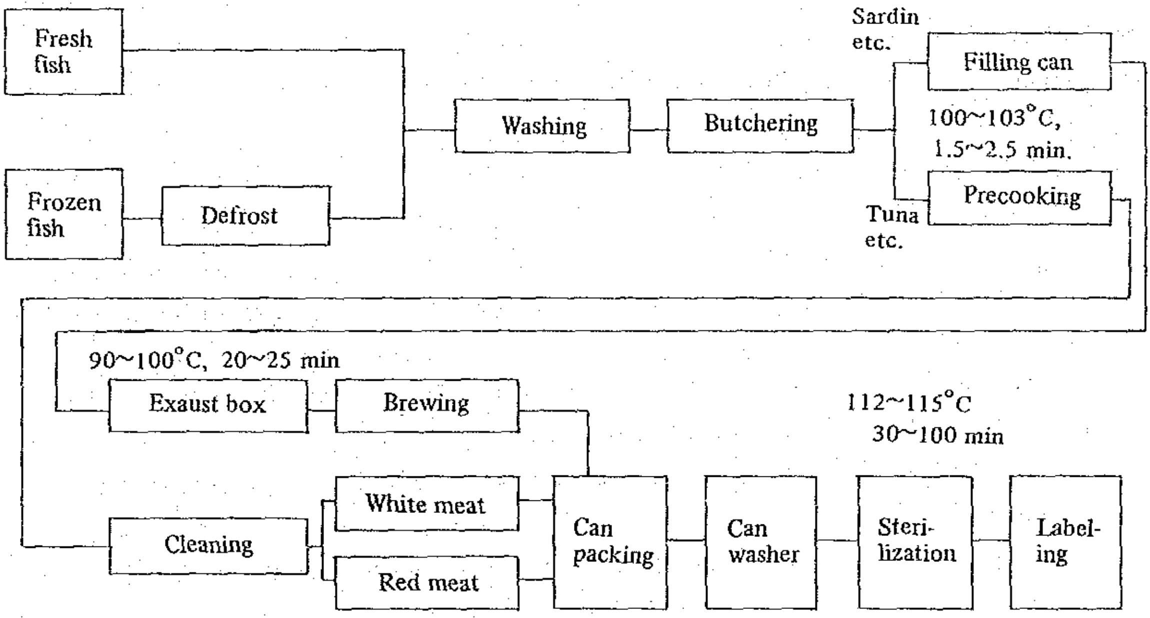


Fig. III–6–2

There are two kinds of raw materials: fresh, and refrigerated. The fresh fishes are immediately put in a washing process, and the refrigerated fishes are fed into a defrosting process.

The defrosting is carried out by running water or by merely water dipping. A large fish is put into a defrosting tank with a processed amount and is allowed to stand for one night until the next day. In Japan, the water quantity required to defrost 1 ton of refrigerated fishes is approximately 3.5 tons. The washing process is carried out by a running water wash in the tank or in a shower wash. The water quantity is approximately 1 ton per 1 ton of fish.

Large fishes such as tuna or bonito are previously steamed for precooking. Fishes are put side by side on the rack of a truck with racks in several steps, 3 or 4 trucks are put into a precooker at a time and steam is blown in directly to cook the fishes. The precooker is usually an internal pressure vessel of the horizontal square box type of 1.5m × 1.5m × (3-5m). The servicing temperature is about 100°C and the cooking time is 1 to 2 hours.

The vapor pressure should be sufficient with 1 kg/cm^2, but some factories have used a vapor pressure of 2-3 kg/cm^2. Most of the cooker's surfaces are not heat-insulated and the drain is discharged into a drainage ditch without recovery. The execution rate of heat insulation in Japan is 50%.

After completion of the precooking, the fishes are allowed to cool (cooling process), the bone and skin are removed and the fishes are divided into white flesh and red flesh. The white and red flesh are each placed on conveyers to be packed in cans. Then a seasoning liquid is added into the can, which is hermetically sealed by a seamer.

Sardine and mackerel are treated by the same washing process as tuna and bonito. They are packed in cans just after the washing, deodorized and degassed by a steam heating of 90 to 100° C for 10 to 20 minutes in an exhaust box, then dehydrated and a seasoning liquid is added. They are hermetically sealed by a seamer.

The exhaust box is an open type steam heater of 5-10m (length) × 1-1.5m (width) × 0.5m (height) and loses much heat. The servicing of steam pressure to a required temperature is 3 to 4 kg/cm^2. This is a problem. It is also a problem that the exhaust vapor and the drain are discharged with no heat recovery.

Pieces of flesh and oil adhere to the completed sealed can surface. These adherent matters interfere with heat transfer because of a low heat conductivity. These cans should be sufficiently washed with a hot water of 50 to 60° C or a hot water contained with detergent before a retort sterilization. For this washing, in some factories the temperature of water is purposely raised by steam.

The retort sterilization must be made extinct even to the spores of heat resistant bacilli as well as the bacilli attached to the canned material.

The countermeasures of energy conservation should be done with a priority being the product quality.

The retort is usually a horizontal cylinderical type internal pressure vessel of (1.3-1.5m ϕ) × (3-6m). The washed cans are packed in baskets attached with a castor and the baskets are put in a retort. When the air in the retort is completely expelled by direct blowing of steam, it is controlled to a predetermined temperature. This is called "come-up". The come-up time takes generally 15 to 20 minutes. Then, sterilization is carried out in a temperature of 110 to 120° C for 50 to 100 minutes. If air of a low heat conductivity remains around the cans, a required temperature can not be obtained and it may result in products of poor sterilization. Every nook and corner of the retort must be heated evenly to the predetermined temperature for a shorter time. This is an important subject for shortening the sterilization process cycle and for the countermeasure of energy conservation.

The heat insulation of retort and the heat recovery in drain and exhaust vapor are also important factors for an effective application of energy.

Waste water treatment facilities in the canned factory should not be ignored from the viewpoint of energy conservation. The operation power cost of the waste water treatment facility should be saved by reduction of new water consumption through a circulating of the process water.

A storage of the raw material in a refrigerator facilitates the control of the production schedule and can make an improvement of the production efficiency. An establishment of effective operation of the refrigerator and a good understanding of cold insulation are required.

2.1.2 Vegetable oil industries

For oil materials vast energy is consumed in the course from harvest to processing including the processes of transportation, handling and storage. If the raw material absorbs moisture in storage, much heat energy will be consumed to dry it. Thus, many subjects to the energy conservation are latent even before the production processes. The raw materials are soybean, sesame, rapeseed, rice bran, cotton-seed, kapok, sunflower, castor bean, and so on. Oil can be extracted by a technique suitable to each raw material.

Most of the pretreatment is through steam heating and the oil separation processes are divided into a mechanical expression and a solvent extraction.

The expression is carried out by an batch system cylinder press or a continuous system press. Crude oil is squeezed out of the material, through pressing, in a heating condition. In the extraction process, the treated raw material is immersed in an organic solvent at a temperature of about 60° C to allow the oil to transfer into the organic solvent. The solvent containing oil (micella) is distilled to obtain crude oil by separation of the solvent.

The expression is simple and does not need much heat energy, but yield is low. Accordingly, the combination with an extraction has been mainly applied to.

Fig. III-6-3 shows the production processes of extraction and expression in a typical factory of Thailand.

Rice bran is cooked in a condition of a moisture of 10 to 20%, a temperature of 90 to 95° C for 5 to 10 minutes as a pretreatment, and then is pressed softly and mechanically by a steaming press. Soybean is pre-dried with a hot air, cooked to suit with extraction.

Castor bean containing about 45% of oil is dried from 5 to 7% to 4% of moisture in a hot air conditioner, and the crude oil is expressed about 35% by a cylinder type press with maintaining a temperature of 60 to 70° C in the bean. From the strained draff the remaining 10% is extracted by a solvent extraction.

The extraction is carried out by a countercurrent of the raw material to the solvent (n-hexane) in a continuous extractor. Oil is extracted at first by the concentrated micella, then by, a diluter micella and finally by contact with a new solvent. The extraction temperature is 55 to 65° C and the solvent or micella is heated indirectly by steam to maintain the temperature.

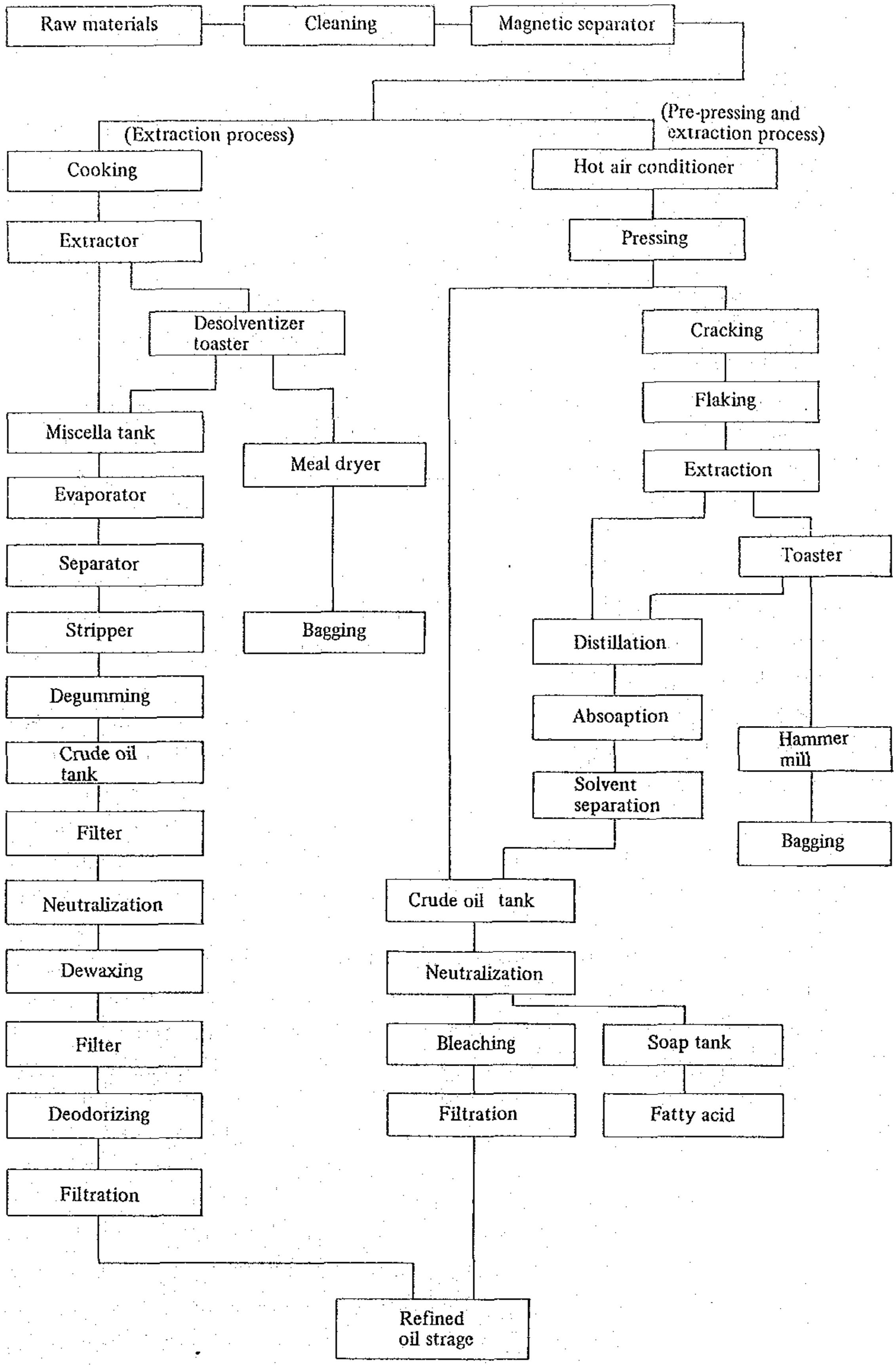

Raw materials
Cleaning
Magnetic separator
(Extraction process)
(Pre-pressing and extraction process)
Cooking
Extractor
Desolventizer toaster
Miscella tank
Meal dryer
Evaporator
Separator
Stripper
Bagging
Degumming
Crude oil tank
Filter
Neutralization
Dewaxing
Filter
Deodorizing
Filtration
Hot air conditioner
Pressing
Cracking
Flaking
Extraction
Toaster
Distillation
Absoaption
Solvent separation
Hammer mill
Bagging
Crude oil tank
Neutralization
Bleaching
Soap tank
Filtration
Fatty acid
Refined oil strage

Fig. III–6–3

The draff taken out of the extractor is charged to the DT column to remove the solvent contained in it by direct contact with steam and falls gradually in the column.

When the draff falls to the lower section of the column, almost all of the solvent is removed, but the moisture is increased. Then the draff is dried to control to a specified moisture content because the draff, after the extraction of oil, is sold as a feed for livestock. In the process, how to use the steam in the DT column effects the energy consumption in the drier.

Oil and solvent in the micella are separated by a distillation column. In the distillation column, it is important that the micella be distilled without any deterioration of oil and with an effective heat utilization. The residence time of micella under heating should be shortened and the processes of evaporation and stripping should be carried out under a reduced pressure in order to lower the treating temperature. Therefore, the distillation column should use a multi-effect system to increase the heat efficiency and the waste heat of the vapor fed from the distillation system of micella should be utilized.

The crude oil is refined in the processes of degumming, neutralization, decoloring, dewaxing, and deodorizing. But the refining of crude oil is carried out by various processes depending on the kind of crude oil or the refining degree required.

Either way, in the refining process the heating and cooling are repeated and much energy is consumed.

(1) Neutralization

Neutralization means to separate fatty acids and non-glyceride impurities by an alkali treatment. Generally, caustic soda is used as alkali. The process is both a batch system and a continuous system. In either system, however, when the crude oil is heated to about 60 to 90° C, added with a little quantity of phosphoric acid and with a caustic soda solution of 15Be in a quantity of about 110% of acid content, and a soap called a "foots" comes out. The foots precipitate easily in standing. In the continuous system, the foots are separated by a centrifuge. Since the oil after centrifuging contains moisture around 0.5%, the oil is dried in a vacuum drier. An approximate utility consumption in the treating 50 t/d of crude oil is required with 200 kg/h of steam, 25 kWh of power and 900 to 1,200 kg/h of process water.

(2) Decolorization

Decolorization aims are elimination of some undesirable colors in the oil.

Generally, these undesirable colors are now eliminated by absorption to an activated clay, an acid clay or a combination with an active carbon. At the same time, a very small quantity of impurities is also eliminated by the absorption and flavor is given to the product.

In a batch system, a vacuum vessel has recently been used to prevent oxidation. The vessel is provided with an agitator, a jacket or coil for steam heating. Oil is put in the vessel and heated. Clay is added (0.5 to 1.5%), temperature is rapidly raised (90 to 120° C), agitated in a suitable temperature (20 to 60 min.) and then passed through a filter to eliminate the clay.

In a continuous system, the Girdler system has generally been applied. A vacuum vessel maintained in 40 mmHg of vacuum is divided into two chambers: the upper, and the lower. Oil heated to 55° C is sprayed into the lower chamber to be degassed and dehydrated. Then the oil passes through a heat exchanger and a steam heater to be more fully heated. The oil is preliminarily decolorized in the first filter, packed with a waste clay, and sprayed to the upper chamber. The oil is mixed with a clay and constantly spouted out of a nozzle, heated to about 110° C, and the clay is separated in the second filter. The oil is fed into a storage tank through a heat exchanger and a cooler. A part of the decolorized oil (ca. 10%) returns to a clay slurry tank. The tank is adjusted so that the clay enters continuously in a proper quantity to make a clay mud of about 25% in the mixture of the decolorized oil. The used clay separated in the second filter is packed in the first filter to utilize the residual discoloring power. For the crude oil treatment capacity of 50 t/d, the utilities are consumed with 425 kg/h of steam, 17 kWh of power and 12 t/h of process water.

(3) Deodorizing

Oil has a peculiar odor and an odorus substance is produced also by the rancidity or the decomposition of the oil and an odor is caused even in the hardening and the decolorization processes. These odors are generally unpleasant and the odorous oil cannot be used for food and cosmetics. These odorous substances are volatile to a certain extent, and can be eliminated by a high temperature distillation under a reduced pressure.

Since the deodorizing process consumes a lot of energy, there are many examples of improvement.

The deodorizing process is a batch system and a semi-continuous system. The batch system requires (1) a long time for deodorizing (5 to 10 hours), (2) a very small quantity of volatile substance remaining is difficult to be eliminated because of a thick oil layer, (3) the volatile substance eliminated once returns in the oil through condensation of it on the wall, and (4) the heat loss is too much. The batch system has rarely been used in Japan.

The semi-continuous system eliminates the weak points of the batch system and the processes of feeding, heating and cooling are automated. The system can treat various oils in succession.

Fig. III-6-4 shows the Girdler's semi-continuous deodorizing column. The column provides trays in 5 or 6 steps. Valves, which can open or close periodically by a timer, are provided among the trays. The pressure in the column is reduced to 2 to 6 mmHg, the oil fed to the trays in the upper step is heated to 160 to 170° C by steam to eliminate the air in oil. In the trays in the second step, the oil is heated to 230 to 250° C by dowtherm. In the trays in the third and fourth steps, steam distillation is performed by blowing of steam (also in other trays, a small quantity of steam is blown in for agitation and degassing). The lower step provides a cooling coil and the oil is cooled to less than 60° C and discharged to the exterior of the column. The oil comes from the product through filtration for finishing.